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PROTOTYPE TESTS FOR A VERTEX CHAMBER*

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Abstract

We describe the design parameters for a pressurized drift chamber under construction for use with the MAC detector at PEP to operate within 3 cm of the beam line. The chamber is constructed of 7 mm diameter tubes of aluminized mylar with wall thickness of 0.10 mm. The tracking device incorporating these tubes is particularly simple to construct and can be configured so that any malfunctioning tube can be remotely disconnected without affecting overall operations.

Resolution studies made in a SLAC test beam with a prototype over a wide range of gases and operating conditions are reported. The resolutions obtained were in the 10-40 micron range.

It was found that the chamber could be operated satisfactorily, using heavily quenched gases, at high pressures ($\sim$4 atm) and operating voltages of $\sim$4 kV in a mode for which saturated streamers were initiated with high efficiency by single electrons. Single electron gains for this mode were $\sim 10^8$. The streamers were confined to a region of the wire with dimension of the order of a few hundred microns and count rates in excess of 10^4 Hz/cm could be sustained with low dead-times.

Further studies are in progress on chamber lifetimes with a variety of gas fillings. For our specific application this is of particular importance as the vertex chamber is expected to run in regions of high radiation backgrounds. As was expected for a chamber with extended cathodes, lifetimes were good. Actual lifetimes observed to date with our tube configurations have ranged from 0.05 coul/cm integrated current on the anode for 50:50 argon–isobutane to $\sim$1 coul/cm for a mix of 49% A: 50% CO_2: 1% CH_4.

The results of these tests show our design goals to be achievable. Additionally they provide a basis on which to design high precision tracking devices particularly in applications where the device is to be operated in regions of difficult physical access or high ambient radiation levels.

1. Introduction

The measurement of a comparatively long lifetime associated with particles containing b-quarks has provided motivation to upgrade the tracking capability of the PEP detector MAC with a Vertex Chamber (VC) of sufficient precision to measure particle flight paths of less than 0.1 mm. The present MAC Central Drift (CD) chamber has a single wire resolution of the order 180–200μm and the first layer of wires is at a radius of 12 cm.

To further refine measurements requires a vertex chamber for MAC with as high a precision as possible and able to fit in between the present CD and the circulating electron beams. Such a detector at small radius will reduce the error associated with projection of the track trajectory to the beam position, and reduce the effects of multiple scattering. However this location will, of necessity, imply a detector capable of operation in a region both difficult to access and exposed to high ambient radiation levels.

Our design objectives are therefore to build a relatively finely segmented detector with an ultimate precision in the 20-50 micron range capable of operating in a high radiation environment. In addition, we require that: a) the VC should be self-calibrating, to the required level of precision, on Bhabha scattering events and cosmic ray tracks; and b) the device should be operational for the next running cycle. This latter requirement ruled out the use of solid state technologies.

To meet these requirements we are building a pressurized drift chamber constructed of wires coaxially mounted in tubes of aluminized mylar. We discuss below some of the details of construction of this chamber and report results of prototype tests using the same modules as are being constructed for the final chamber.

2. Design Considerations

Monte Carlo studies[1] based on the programs and work of Va'Vra[2], Jaros,[3] Boyarsky[4] and others, give the requirements necessary to obtain high resolution with drift chambers. Briefly they can be summarized as follows:

(a) The use of high gas pressures and short drift distances to minimize the effects of diffusion on the drifting electrons. High gas pressures also provide good statistical track localization and minimize geometric effects due to ionization density fluctuations along the trajectory of the particle.

(b) The use of good electronic signal processing. For short drift distances this translates into an ability to time on the first or near first arriving electron. Such a requirement necessitates high gain operation of the chamber and low cross-talk from neighboring channels so that they do not cause spurious pulses.

(c) The use of a gas with good diffusion characteristics. In our tests a relatively wide range of standard gas mixes have adequate diffusion characteristics to provide good resolution.

To date the best chamber lifetimes have been associated with the use of flat cathodes as opposed to field wire configurations. Cathode and anode degradation is inhibited by the use of inert gases. The addition of alcohol can sometimes be beneficial.[5]

We considered designs based on the "Jet Chamber" or "Micro-Jet chamber"[6] and the "Straw-Chamber" (ie a chamber of small diameter coaxial wire tubes) of the HRS collaboration.[7] We have chosen the straws design. In the following, we summarize the points which led to this decision.

First, we list some possible disadvantages of the tube technique, and our answers to them:

1. The variable electric field. This can be obviated by the use of a saturated gas or by calibration of the time distance relationship.
2. Mechanical alignment problems. This we believe we have solved satisfactorily and that the chamber at present under construction locates wires to better than 15 microns and cathodes to better than 50 microns largely eliminating problems arising from electrostatic wire movements.
3. Reduction of resolution near the wire. Under pressurized operation this region is confined to within about 50 microns from the wire center. In the small celled straws design, this region affects more tracks than in a large cell design.
4. Multi-hit problems. The cylindrical geometry insures that the arrival times of electrons from a second track will always overlap with electrons collected from a first track. This makes the tube geometry incompatible with multi-hit capability at the one-electron level. With fine enough segmentation, however, this will not be a major problem. Furthermore, using overlapping tubes will allow resolution of many of the double hit configurations. This obviates the need for complex electronic processing.

The above potential problems, when confronted as indicated, appeared to be outweighed by a number of potential advantages provided by the tube technology. The most important of these are:

(a) Chamber construction based on tubes is inherently simple. Each tube can be independently tested in place and the chamber can be designed so that any malfunctioning tube may be separately disconnected without affecting overall operation of the system.

(b) The tube configuration provides a large cathode area and minimizes cathode associated problems. It further functions as a cylindrical transmission line which is comparatively well shielded against cross-talk between neighboring elements and can be terminated with its characteristic impedance.

(c) The cylindrical geometry has the optimal collection geometry for timing off the first arriving electron.

(d) Finally, the identical cells (*ie* tubes) can be easily calibrated.

The HRS design for tubes used 0.075 mm mylar wall thickness. We adopted a slightly more conservative 0.10 mm wall thickness. For some applications this may represent an undesirable addition of material but for our high pressure operation the additional material added by the tube walls was relatively small.

3. Shielding Design

A full discussion of the shielding configuration awaits results from running the chamber in the fall PEP cycle. However as the chamber design is strongly affected by the requirements of integrating the chamber with the beam pipe and shielding we outline considerations that enter into our design of the current shielding configuration.

In a previous period of MAC running using a small diameter (5 cm) beam pipe the radiation levels were largely accounted for by electromagnetic splash from electrons that produced bremsstrahlung in the long interaction region (IR) and were overfocussed by the low-beta quadrapoles so that they pass through the IR. Our present design incorporates substantial heavy-met and lead shielding around the beam-pipe close to the IR to minimize this effect.

Lesser problems in this early run were introduced by synchrotron photons scattering from the shielding and beam-pipe. This radiation could be more serious for us because to minimize the effect of multiple scattering our beam pipe will be constructed of beryllium and will also serve as the wall of the pressure vessel containing the vertex detector. To overcome the greater transparency of the beam pipe, we are lining the beam pipe with a 50μm cylinder of titanium to attenuate these photons.[8]

Fig. 1. shows the beam pipe, shielding and VC which will be mounted as a unit. This shows the "hard-backed" structure required to support the beam-pipe, shielding, tantalum scrapers and the outer pressure wall of the VC enclosure. The gas volume is connected at both ends to feed pipes to permit both flow-through of gas and operation by filling and sealing off the chamber for extended time periods with remotely operated solenoid valves.

Shielded cable bundles penetrate the pressure vessel walls to the inner vertex chamber through epoxy plugs (potted in vacuum) via viton O-ring seals. The prototype chamber incorporated identical detailing for cable penetration and no problems were encountered in operation.

Finally, part of the main shielding will be active detectors in the form of BGO (bismuth germanate) crystals. These will maintain the small angle calorimetry coverage of MAC.

It is clear from this layout that to be compatible with the shielding and existing central drift chamber the vertex chamber can only be accessed with great difficulty and very little space exists for close in electronics. Therefore the ruggedness requirement needed especially to be met.

4. Description of Straws and the Chamber Layout

The straws were obtained commercially, with the assistance of the HRS group, and consisted of two layers of 0.05 mm thick aluminized mylar, cut in strips, and wound spirally on a mandrel of diameter 7.9 mm. The surface resistivity of the aluminum coating is $0.8\Omega_{\square}$. The layers were held together by contact cement. The tubes as delivered by the manufacturer maintained remarkably high tolerances, inner diameters being good to better than 10μm and in general were straight to better than 100μm. They were selected for cleanliness and lack of blemishes, and cut to 43 cm lengths.

These straws were then mounted on a spool consisting of a 0.5 mm thick beryllium tube with 1.6 cm thick aluminum end pieces drilled with 3.45 mm holes for the straw mounting fixtures. The first layer has a total of 40 straws, with no more than 25μm clearance between them. The second layer also has 40 straws, fitted in a close-packed configuration with the first, so that the dead space between straws in one layer is covered by a wire in the other. This pattern insures that if two tracks occur in one side of a straw, so that only that closest to the wire is recorded in layer 1, the second will be that recorded in layer 2 (being closest to the wire there.) The third and fourth layers each have 54 straws, configured as in the inner layers, and the fifth and sixth layers, each 68 straws. A drawing of the end-plate is given in Fig. 2, and a photograph of the chamber under construction is shown in Fig. 3.

A detail of the mounting of straw and wire is shown in Fig. 4. An aluminum collar is glued with conductive silver epoxy to the inside of the straw, capturing a delrin plug, which is threaded and slotted for gas flow through the endplate. Electrical ground contacts to the straws are made directly from the collar to the endplate on one end, and on the other, made via a spring between collar and endplate. The plugs are held by nuts on the threaded parts of the plugs extending through the plates, and these are adjusted for about 500 g force on the straw. The plug is drilled for the insertion of a metallic feed-through, with a 100μm hole to accommodate the wire, and this is seated in the plug as shown in Fig. 4.

After the straws are mounted, the 30μm gold plated tungsten wire is drawn through on a larger wire, threaded into the feed-throughs, one end crimped in place while the other end passes over a pulley and has a 100 g weight attached. That end is then crimped. The tension is checked by placing a magnet near the straw and driving an oscillating current through the wire. This causes the wire to resonate at a frequency proportional to tension. If this tension is out of tolerance the wire is restrung.

It should be noted that the alignment of the straws themselves is measured at the mounting stage to better than 25μm.

5. Electronics

The VC will be mounted inside the MAC detector, and will have directly coupled coaxial cables running to the outside of the device from one end of each tube. The other end of the tube will be terminated with a 330 ohm resistor AC grounded with a 6kV 100 picofarad capacitor. The coax serves as both a signal and positive high voltage connection. RG179B was chosen for its small size (2.8 mm), high voltage capability, high characteristic impedance of 75 ohms, and its heat resistance. Each cable will be decoupled from high voltage by a capacitor, and its signal amplified by a preamp made by LABEN of Milan, and then run into a two level amplifier-discriminator. The two levels are provided so that the lower level discriminator output, suitably delayed, is gated by the higher level discriminator. This system will reject hits without sufficient amplitude to be from real tracks, but will provide the required near-single electron trigger required for best resolution. The discriminator outputs will provide stops for our standard time-to- voltage converters, and these will be read by the existing MAC scanners. A beam induced signal will provide the start pulse for this system.

The mounting and connections of the prototype chamber were similar to the above but used home-made preamps followed by further standard SLAC amplifiers (with a gain of 60) and Lecroy TDC channels. Pulse height information was also recorded, as described in the following section.

6. Prototype Tests

A prototype of 16 straws, in a 4 by 4 array, was constructed for use in a test beam. The prototype incorporated the components and cabling to be used with the full detector. The purpose was to test construction techniques, to determine the limits to the resolution of the final detector, to check cross-talk, and to examine the dependence of resolution on gas mixture, pressure, high voltage, and pulse discrimination levels.

The straws were mounted between two end-plates on an aluminum beam using the precision mounting techniques already described. The wire spacing interval was 7.2 mm and the inside straw radius was 3.45 mm. The central wires were 20 μm gold plated tungsten. The prototype was mounted inside a plexiglas tube with endplates capable of withstanding high pressure, and the 16 high voltage coaxial leads from the wires penetrated the endplates through an epoxy plug. The protype was run in a SLAC test beam with an 8 GeV/c unseparated negative particle beam from a beryllium target bombarded by electrons from the SLAC linear accelerator. The beam was composed of roughly equal numbers of pions and electrons. The prototype was placed immediately after the final collimator, where the beam was parallel to a few milliradians, and about 3mm in width. A small scintillator was placed in the beam ahead of the pressure vessel to provide the time zero signal. The test setup is show in Fig. 5.

The electrical circuit used to power the prototype and record the signals is shown in Fig. 6. The tungsten wires were run at positive voltage, while the cathodes, consisting of the aluminum layers on the mylar straws, were at ground potential. One end of each straw was terminated through a 100 pf capacitor by 330 ohms, while the other was connected to a total of $\sim$ 5 m of 75 ohm coaxial high voltage cable. This cable was decoupled from the high voltage supply by a 1000 pf capacitor, and ended in a preamplifier and cable driver, shown in Fig. 6. The signal was split into two paths, one to an amplifier, a LeCroy 623B eight channel discriminator and thence to a LeCroy 2228A sixteen channel Time to Digital Converter (TDC), while the other led to a LeCroy 2249W Analog to Digital Converter (ADC).

The scintillation counter signal was use as the common start pulse for the TDC's, for the gating of the ADC's and to interrupt an LSI 11/23 computer which read the CAMAC output of the TDC and ADC modules. Data taking was done through the "Atropos" system programs[9] developed at SLAC. Online histograms were made, and a data tape written for further work.

An additional test setup used a small "staggered straw" arrangement consisting of a single layer of straws with three spaced as before but with the fourth straw offset by one straw radius. This device was inserted into a small test box that could be evacuated or pressurized. This additional test rig was easy to modify and was used to check the effects of differing wire radii on resolution and performance, and for calibration of the time-distance relationship.

7. Behavior of the Output Pulses

As noted in the introduction, an optimal strategy for obtaining best drift time resolution over small drift distances is to use the arrival time of the first electron[2]. This requires high gas gain and/or high quality preamps to ensure that single electron signals exceed the electronic noise. In the prototype tests we investigated performance both at relatively low gains in the proportional mode, at moderate gains in the saturated proportional mode and at high gains where single electrons caused the creation of Limited Streamers.[10] Tests were made in the range 1–4 atmospheres absolute pressure.

The gases used for the tests were Argon-Ethane in a 50:50 mixture, Argon-Isobutane in 75:25 mixture, and Argon-Carbon Dioxide in 75:25 mixture. We were able to observe Limited Streamer (LS) pulse production in all gases except for the last. Most stable operation at high gains was obtained for the highest pressures.

We used an Fe^{55} source, with its 5.9 KeV X-ray emission (from the manganese K line) to provide a calibration signal. This radiation could penetrate the thin straw wall and release ~ 240 electrons in a single cluster.

Additionally we used pulses produced from single electrons by photo-emission from the cathode surface to provide single electron calibrations. Light from a source such as a flashlight or light bulb could penetrate the thin aluminized mylar and eject, via the photo-effect, a strong flux of electrons from the aluminum cathode. The actual photo-sensitivity of the cathode surface depended strongly on the previous history of the cathode surface. With this technique we could observe simultaneously both the response to Fe^{55} pulses and to single electrons. The single electron signal was also used on-line to calibrate discriminator levels directly in terms of number of electrons required to trigger the TDC's.

As a function of voltage, the pulses observed from a test straw showed transitions from the proportional mode to saturated proportional mode and LS mode at critical voltages depending on gas and pressure. Remarkably enough, with highly quenched gases that would normally be classified as being in the saturated proportional mode with slow increases in Fe^{55} gain as a function of voltage we observed that single electron induced pulses showed a discontinuous jump in gain at some critical voltage characteristic of limited streamer operation. Beyond this transition the single electron induced pulses became identical or close to identical to those induced by Fe^{55}. The pulses also had the characteristic very fast rise and fall times (<3 nsec) associated with streamer formation.

Illustrative of this combined mode are typical results shown in Fig. 7. It shows the mean pulse heights observed in these tests as a function of straw voltage. Note that although the single electron response increases by almost two orders of magnitude at the LS threshold, the Fe^{55} pulses are already saturated and do not change appreciably.

The characteristics of this mode differed also in another essential respect from restricted streamers observed at lower pressures by other authors.[10] Pulses associated with a Sr^{90} beta-ray source producing non-localized ionization did not give predominantly single streamers, as observed at one atmosphere, but gave large variable pulses in time and pulse length roughly ten times those produced by Fe^{55}. This corresponds to a streamer pulse producing a deadened region with a spatial extent confined to only a few hundred microns, and an ionizing track producing a number of separated streamers. The sense wire could support count-rates in excess of 10^4 Hz/cm without appreciable dead-times.

The voltage-plateau for these single-electron streamers depended on the gas used. Characteristic regenerative breakdown pulses, separated in time by the electron drift time from anode to cathode were seen and clearly arose from UV photons, produced in the initial avalanche, causing photo-emission of electrons from the cathode. The cathode photo-sensitivity decreased and the gain plateau increased significantly with running. (We could not distinguish whether this change was caused by surface clean-up or surface contamination). Typically, after "running-in" a straw, plateaus for single electron streamers were of the order of 800 volts for heavily quenched gases at 4 atmospheres.

Smaller wire diameters ($20-40\mu$m wire diameter) showed the combined property of long plateaus for both "saturated" gain for large pulses and "saturated streamer" behavior for single electrons. These wire diameters therefore provide an option of running in either mode. For this reason we chose to use 30 micron wires for use in our final chamber.

The use of LS pulses in drift time measurements has advantages aside from the obvious one of high gain ($\sim 10^7 - 10^8$.) These pulses are quite uniform, and have small initial rise times resulting from electron collection (not ion drift) shorter than a few nanoseconds. In the saturated proportional mode pulses from minimum ionizing particles are 50-100 times the amplitude of those from single electrons. Crosstalk must be $<1\%$ to reliably trigger on the first electron. Since in the LS mode the first electron produces almost the entire pulse height, thresholds can be raised, and crosstalk requirements can be relaxed.

The main problem from the use of very high gains ($\sim 10^8$ for single electrons and the associated average pulse gains of 10^7) is chamber degradation. High gain coupled with a high radiation environment must result in a large average DC current drawn by the chamber and eventual collapse due to impurity layers deposited on either the cathode or anode. This is discussed in the section on lifetime tests and we have found a gas mixture combining excellent gain characteristics, a long single electron LS voltage plateau and excellent lifetime properties. The gas mix in question is 49% A: 50% CO_2: 1% CH_4.

8. Time and Position Resolution Studies

8.1 CROSS-TALK

In the following subsections, we present studies of position resolution which can potentially be realized in practice if the problem of cross-talk between channels can be handled. The magnitude of the problem of course depends upon the particular electronic circuitry used.

In our test setup we measured crosstalk matrices for the entire system and its parts. Elements in the system matrix ranged from 0.3% to 1.5%. The crosstalk was traced to incomplete shielding by the aluminum layer in the straw and to common grounding at the preamp output, in roughly equal parts. An upper limit of 0.5% is feasible. Some crosstalk pulses were inverted with respect to the primary pulse, some were not, depending on the channels. The crosstalk pulses were highly differentiated and frequency dependent: figures are quoted for signals from the 5.9 KeV X-rays. Crosstalk is less for slower pulses. Timing from crosstalk pulses is significantly slewed with respect to the primary pulses, because the crosstalk pulses are small and often inverted.

8.2 ARGON-ETHANE, 50:50

Extensive measurements were made with the standard Argon-Ethane 50:50 gas mixture. Tests were made at 1, 2, 3 and 4 atmospheres absolute pressure, with voltages spanning if possible the LS threshold, and at various discriminator settings.

Results can be seen in a very graphic form from scatter plots of arrival times on one straw versus another straw.

Fig. 8 displays a scatter plot for the staggered straw array of the arrival times for straw 4, the offset straw, versus the arrival time for straw 1. If the drift velocity were exactly constant then the sum of the two times divided by the drift velocity would equal the offset between the two wires. The scatter plot shows a correlation very close to that expected for a constant drift velocity. Analysis of the small departures from linearity and use of the known straw offset permits an accurate determination of the drift velocities as a function of position within the straw. Obviously the resolution as a function of position can also be determined.

Fig. 9 displays results from the 16 straw prototype tilted at an angle of 29° to the beam. This figure shows arrival times for straw 1 versus straw 4 for the Argon Ethane 50:50 mix at 4 atm. A very loose cut was made to minimize backgrounds by demanding a threefold coincidence in the straws. Three regimes are apparent. Tracks crossing the array above the two wire centres give a close to linear correlation and those crossing below both wires give an offset linear correlation. Tracks passing between the two wires are correlated so that the sum of the two time displacements is approximately constant for a saturated drift velocity. These three regimes are cleanly seen in Fig. 9. Additionally the behavior of tracks passing close to either of the wires can be seen from crossing times close to zero. A track going through the centre of a sense wire will form its first cluster at a distance from the wire and will give a non-zero arrival time. This results in a clearly observable statistically systematic displacement $\sim$1 nsec or 50μm in the vicinity of the wire. The observations are in agreement with predictions based on a detector threshold corresponding to the first electron arriving at the sense wire.

Use of the information from three straws permits small effects from non-parallelism of the beam to be corrected for. To fully analyze the data we used the following procedure. The passage of an 8 GeV/c particle through the drift cells was signalled by the occurrence of a scintillator pulse, which initiated the reading in of TDC and ADC information. True tracks were selected by requiring either 4 TDC digitizations, or 3 TDC values in the case of determination of efficiency, within a "roadwidth". The roadwidth was defined as the mean residual of a fit of a straight line through the time readings, which in the case of 4 straws was just $0.5\sqrt{\chi^2}$. The roadwidth cutoff was chosen generally to be large, in order not to cut off the tails of the distributions. A typical distribution is shown in Fig. 10 where the cutoff value is indicated by an arrow.

For the data selected in this way, Fig. 11 shows the distribution of the quantity

$$R = \sqrt{\frac{2}{3}}\left(\frac{t_1 + t_3}{2} - t_2\right)$$

which can be shown to have the variance of the single wire resolution. It can be seen that the distribution is well described by a gaussian curve. We have generally chosen to interpret the rms of the distribution as the single wire resolution, although it is generally larger than that obtained by fitting a gaussian. To convert time to position resolution for Argon-Ethane, we have used a velocity of 50μm/nsec.[11] The result of Fig. 11 indicates a single wire resolution R of 20μm.

The results of similar analyses at other pressures, voltages, and discriminator levels are summarized in Fig. 12. The highest voltage at each pressure was in the LS regime. Here the resolution is essentially independent of the discriminator level. As voltage is reduced, R increases and becomes sensitive to discriminator level. At 4 atmospheres, resolution is excellent over a considerable range of voltages. At 1 atmosphere, the resolution does not appear to reach a "saturation" similar to that of the higher pressure, and gets rapidly worse with decreased voltage.

The relative independence of resolution and discriminator level in the LS regime confirms the conclusions of the previous section that the first electron to drift to the wire controls the rising edge of the pulse. However, it should also be noted that at high pressures resolution is not degraded by very much if one is forced to run in the proportional mode, as long as voltage is near the LS threshold.

We have tried to include the effect of cross-talk in Fig. 12 by showing the points connected by curves which becomes broken when the cross-talk, as defined above, exceeds 10%. As can be seen, an acceptable cross-talk level can be achieved without loss of resolution, at each pressure, by adjusting the threshold setting.

The dependence of resolution on distance from the wire is shown in Fig. 13, at two voltages and discriminator levels. The best overall result is at 4 kV, in the LS regime, where the effect of diffusion is small but visible. At 3.7 kV, the proportional regime, resolution is only slightly worse but shows an expected deterioration near the wire, especially at high discriminator level. This is because the electron cloud reaches the wire substantially more slowly than for tracks away from the wire, and the leading edge of the pulse is more ragged. These results are compared to a Monte Carlo study of the straws system which will be presented separately.[1] Agreement is good for a choice of $\sigma_d = 170\mu\text{m-cm}^{-\frac{1}{2}} / \sqrt{P}$ (a value that agrees with a direct independent measurement of this quantity by us).

We have also explored the effect of tracks traversing the straws at an angle to the long axis of the straws. The resulting resolutions as a function of angle are shown in Fig. 14a. It is clear that the increase in effective ion density along the projected track path with angle gives improved resolution. Fig. 14b shows the time resolution curve obtained at $\theta = 70°$. It is double peaked because the fourth wire of the array had a 50μm offset with respect to the other three. This made it possible to measure the very small resolution numbers.

8.3 ARGON-ISOBUTANE, 75:25

Argon-Isobutane mixtures are promising because the heavy molecules are good quenchers. We tried a 75:25 mixture in conditions essentially identical to those used for the data of the previous section. The transition from proportional to LS modes occurred at roughly the same voltage as with the Argon-Ethane mixture.

The results for resolution are so close to those of the previous mixture that we do not show them. We conclude that this mixture would be interchangeable with the other.

8.4 ARGON-CO_2, 75:25

To obtain good lifetimes of the detector in a high radiation environment it could be imperative to use inert gases. An excellent contender is Argon-CO_2. We tried this in a 75:25 mixture at 2 and 4 atmospheres pressure.

This mixture does not have a saturated velocity characteristic, but does appear to have a high field plateau, although the literature is inconsistent in actual values. We have used the values of Ma *et al*[12] and when converted for our straw geometry and 3300 volts, a velocity dependence on radius results which is shown in Fig. 15a. In Fig. 15b we show our data for this voltage, with time converted to distance according to the velocity profile.

At 2750 volts, resolution has already deteriorated by $\sim 50\%$.

9. Chamber lifetimes

An important factor in design of vertex chambers is the ability to function under high background conditions. We are therefore currently exploring the properties of a range of suitable gas mixes. We expected, and have observed, that the use of "flat cathodes" permits the achievement of relatively long lifetimes against tube degradation.[5]

If lifetime tests are to be completed in a finite time they must be run at substantially higher rates than will be encountered with the actual apparatus. Such tests, almost certainly cause non-linear degradation of tube performance and place lower limits to the lifetimes than are likely to be observed under real running conditions. Our tests are made at 4 atmospheres pressure with a 10μCurie Fe^{55} source placed next to the walls of the straws. The high–voltage applied is sufficient to produce saturated streamer mode pulses at gains corresponding to

$\sim$150 millivolts into 50 ohms. The pulse rate is $\sim$30,000 Hz corresponding to 1-2 μA per cm of wire. The test straw is contained in a sealed pressurized vessel. The geometry and conditions obviously differ in significant respects from other previous tests,[10,13] including the use of pressure, very high gains and a sealed off gas volume.

Gases containing a large proportion of hydrocarbons such as ethane or isobutane went into continuous discharge after integrated currents of 0.05 coul/cm. This discharge was caused by degradation of the anodes by the formation of a spike or whisker. If a new anode wire was inserted in the straw it would run for a similar period indicating that the problem was unconnected with the cathode.

Argon:CO_2:CH_4 49:50:1 is the best gas mix tested to date, with a lifetime of $\sim$1.0 coul/cm. Argon:CO_2 50:50 gave a shorter lifetimes of $\sim$0.5 coulombs/cm.

We are experimenting with the use of xenon as an additive[14]. We have observed clean single-electron streamer mode operation with a plateau of 900 volts and an ability to sustain currents in excess of 6μA/cm in argon:xenon:CO_2 30:20:50 at 4 atmospheres pressure, without any added hydrocarbon quencher.

In addition to the enhancement of avalanche multiplication by a large factor through the Penning effect xenon appears to quench UV feed-back,probably via its hard UV absorption bands centered at 1400 and 1200 AU.[15]

Despite the absence of hydrocarbons we observed anode degradation in this gas mixture after 0.5 coulombs/cm. This degradation was associated with a disappearance of the voltage plateau for streamer operation but did not affect resolution in proportional mode operation in a standard 90:10 argon methane mixture.

Factors limiting lifetimes are clearly complex and we are continuing to investigate these questions.

10. Conclusions

The results of resolution studies show good agreement with Monte Carlo predictions [1] when values for the longitudinal diffusion constant of about 170μm-cm$^{-\frac{1}{2}}$-atm$^{\frac{1}{2}}$ are used.

The resolutions obtained under a wide variety of conditions for gases pressurized to 4 atmospheres in a tube or straw configuration lie in the range 10-40 microns. At this level experimental precision is likely to be limited not by track resolution but by multiple scattering and other such constraints.[16]

We have obtained the required mechanical tolerances in our prototype studies and expect to maintain them satisfactorily in the chamber we are fabricating. Our fabrication methods are simple and to date have proved to be satisfactory.

Straws can be operated at very high gains and can be used in a mode giving single electron saturated streamers combined with strongly saturated Fe^{55} pulses. This mode shows other qualitative differences from the restricted streamers observed at lower gas pressures. The streamers appear be confined to a region with spatial extent of only a few hundred microns and count-rates in excess of 10^4 Hz/cm do not cause appreciable deadtimes.

Lifetimes for straws are good and similar to those observed for flat-cathode detectors used in other applications. The best gas we have found to date for lifetime is Argon:CO_2:CH_4 49:50:1 which gave a lifetime before degradation corresponding to an integrated charge on the anode of $\sim$2 coul/cm.

In summary we believe that pressurized drift chambers using straws can provide high resolution coupled with good segmentation and relatively long chamber lifetimes even in high radiation environments. The assembly of such chambers is relatively simple and loss or degradation of performance of individual wires should not affect the overall performance of the chamber.

11. Acknowledgements

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REFERENCES

(a) Present address: Los Alamos National Laboratory, Los Alamos, New Mexico, 87545

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1. G. Chadwick and F. Muller, MAC-NOTE 683, Feb. 1984.

2. J. Va'Vra, SLAC-PUB 3131, June 1983.

3. J.A. Jaros, Stanford 1982, Proceedings, Instrumentation for Colliding Beam Physics (1982); SLC Workshop Note No. 51, Dec. 1981

4. A. Boyarsky, SLC Workshop Note No. 2, Feb. 1983

5. G. Charpak *et al.*, Nucl. Inst. Meth. 99, 279 (1972).

6. H. Drumm et al, IEEE Trans. Nucl. Sci. Ns-28(1979)80.

7. D. Rust, SLAC-PUB-3311, April 1984

8. C.T. Hoard, SLAC-TN-82-3, October 1982.

9. C. Logg and P.W. Clancey, SLAC Electronics Dept. ELDDOC No.25, 1983.

10. E. Iarocci, Nucl. Inst. and Meth. 217,30 (1983); M. Atac and A.V. Tollestrup, Preprint FN-339, Fermilab (1981); T.A. Mulera and V. Perez-Mendez, Nucl. Inst. Meth. 203, 609 (1982); T.A. Mulera *et al*, IEEE Trans. Nucl. Sci., NS-30, 355 (1983)

11. see, eg, J. Fehlmann *et al*, Compilation of Data for Drift Chamber Operation, ETH ZURICH, HPK, TEC DETECTOR GROUP, July 1982. We have also measured this quantity directly.

12. C.M. Ma *et al*, MIT Technical Report 129 (1982), as given in the compilation of Ref. 11.

13. A.H. Walenta, Proceedings of the 1977 Isabelle Summer Workshop, p. 41, (1977); Results of Fischer, Sobottka and Walenta, quoted by H. Okuno *et al* in Proceedings of the 1978 Isabelle Summer Workshop, p. 139 (1978); H.J. Hilke, Proceedings of the 1981 Isabelle Summer Workshop, p. 1275 (1981)

14. R.Z. Fuzesy *et al*, Nucl. Inst. Meth. 100, 2567 (1972.)

15. G. Baldini, Phys. Rev. 128, 1562 (1962).

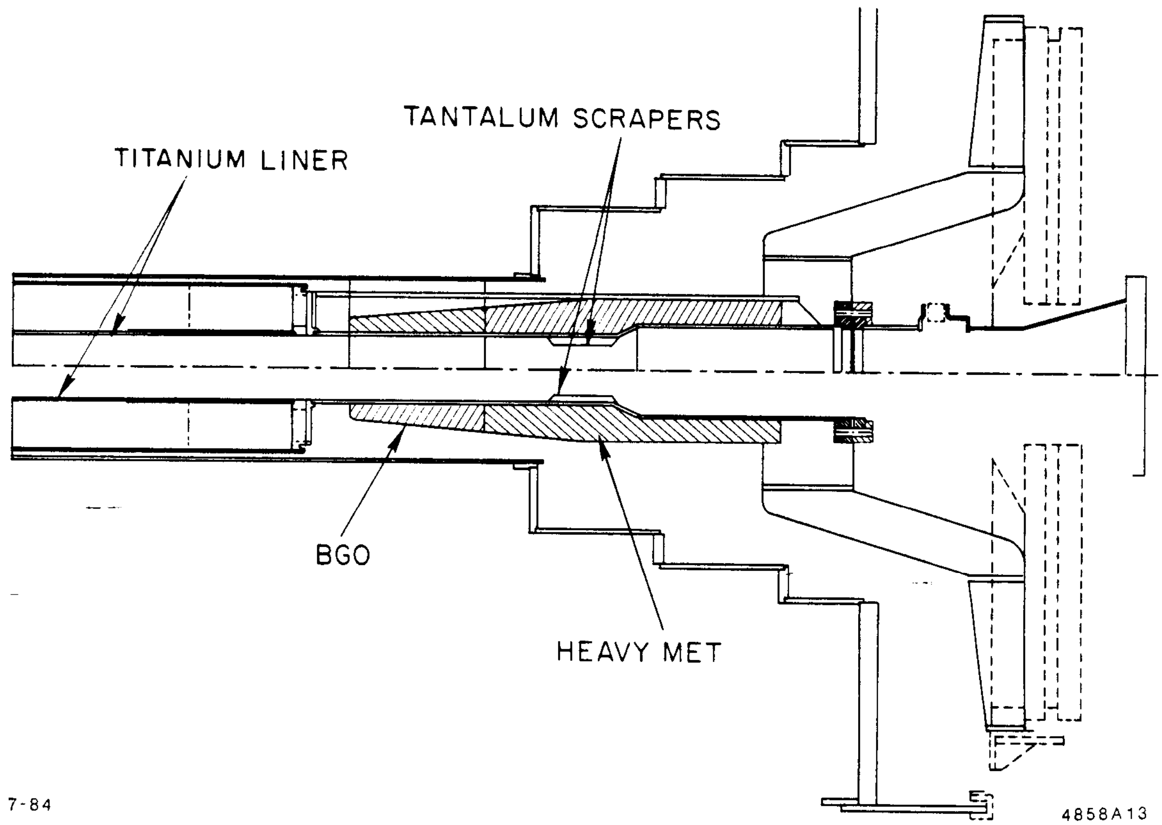
16. G. Chadwick, MAC-NOTE No. 688, Feb. 1984.

FIGURE CAPTIONS

1. Cross section of the MAC Vertex Chamber, shielding and beam pipe assembly, showing the tantalum scrapers, heavy-met absorbers, and titanium liner.
2. Layout of the vertex chamber end-plate, showing the arrangement of the 6 layers of tubes.
3. Photograph of the vertex chamber under construction.
4. Detail of the mounting method for straw and wire.
5. Photograph of the prototype array of straws used in the tests.
6. Schematic of the electrical circuit used in the prototype tests of the MAC vertex chamber.
7. Mean pulse height as function of voltage in Argon-Ethane at 4 atm.
8. Drift times for two straws offset with respect to the beam by one radius, plotted one versus the other. For constant velocity, their sum is constant.
9. Drift times for two straws tilted at an angle of 29° to the beam, plotted one versus the other. The region of constant sum for the times is smaller and two regions of constant difference emerge.
10. Roadwidth distribution for Argon-Ethane 50:50 mixture at V=4.15 kV, Discriminator 75 mV. The cutoff for selection is shown by the arrow.
11. Distribution of the resolution quantity R, for Argon-Ethane at 4 Atm, V=4.15 kV. The curve is a gaussian fitted to the data, with $\sigma = 0.4$nsec, corresponding to 20μm resolution.
12. Average single wire resolution as a function of voltage scaled by pressure for various pressures and discriminator levels. The curves are to guide the eye.
13. Dependence of resolution on distance from the wire, for Argon-Ethane 50:50 mixture at 4 atm. The solid circles are for 4 kV at which pulses are in the LS regime. Open circles and crosses are for 3.7 kV, proportional mode. Here resolution is not markedly worse, but the region near the wire shows deterioration, especially at higher discriminator level. The line is the result of a computer simulation study[1] of pulse formation by ionization in straws.
14. a) Single wire resolution of the straws as a function of the angle θ from

normal incidence. The increase of effective ion density with angle appears to give considerable improvement. b) Time resolution curve for the 70° data. The curve is a fit to a double gaussian distribution with one variance, used in obtaining the resolutions of (b). The separation results from a 50μm offset of the fourth wire.

15. a) Velocity profile of Argon-CO_2 mixture in our straw field configuration used to determine resolution. b) Resolution found as function of track distance from the wire.



TANTALUM SCRAPERS
TITANIUM LINER
BGO
HEAVY MET
7-84
4858A13

Fig. 1

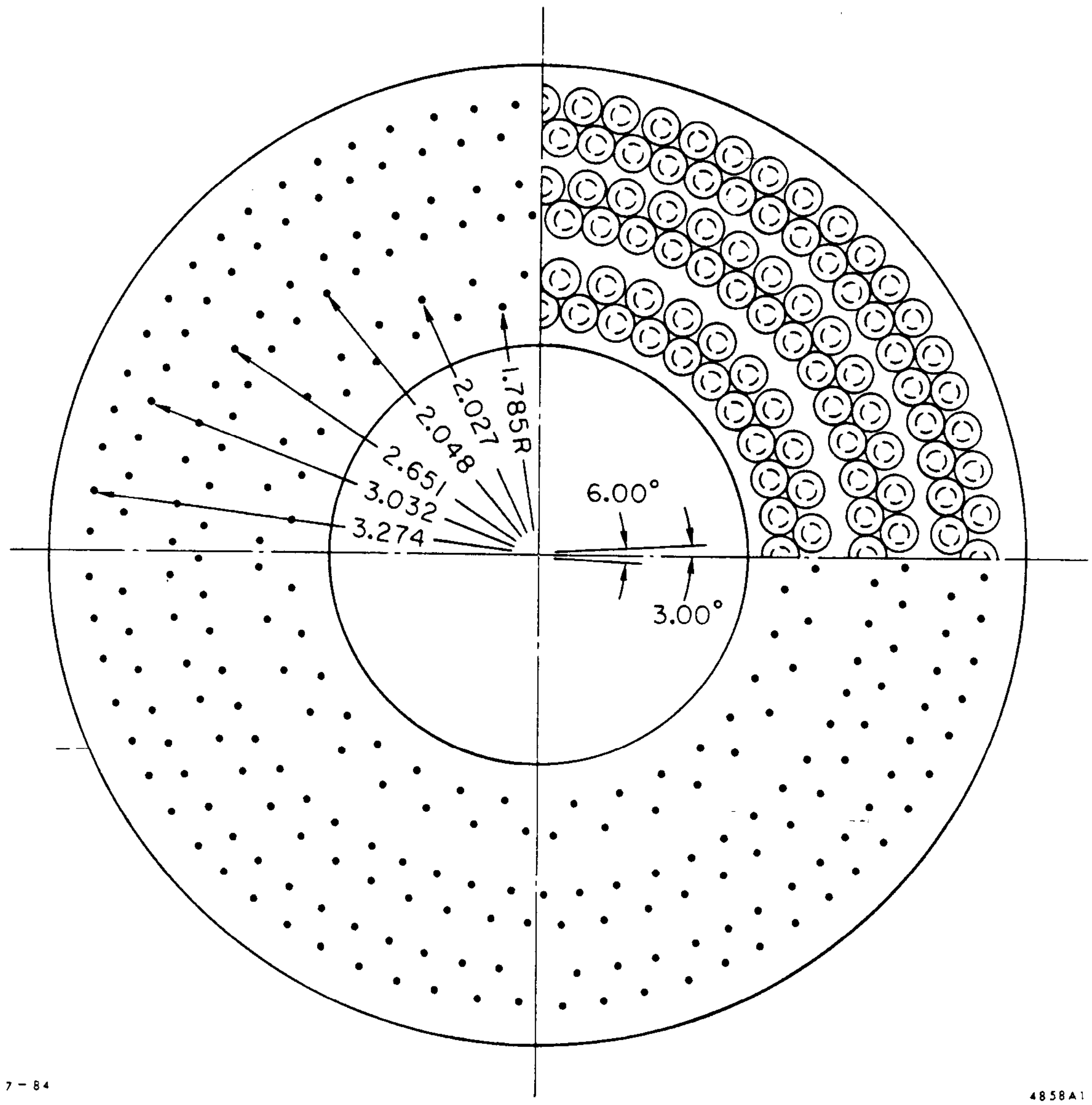


Fig. 2

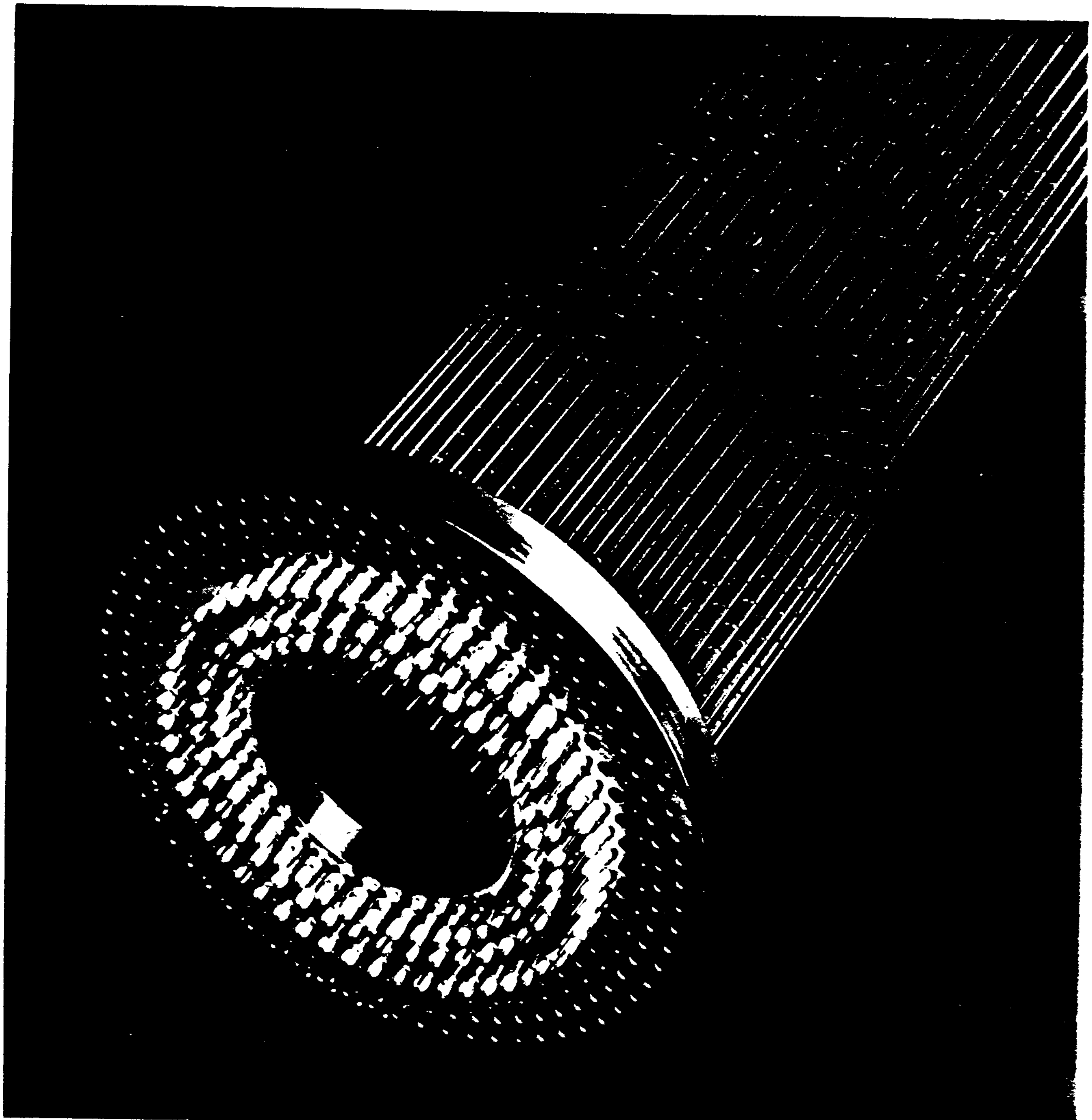

8-84 4858A14

Fig. 3

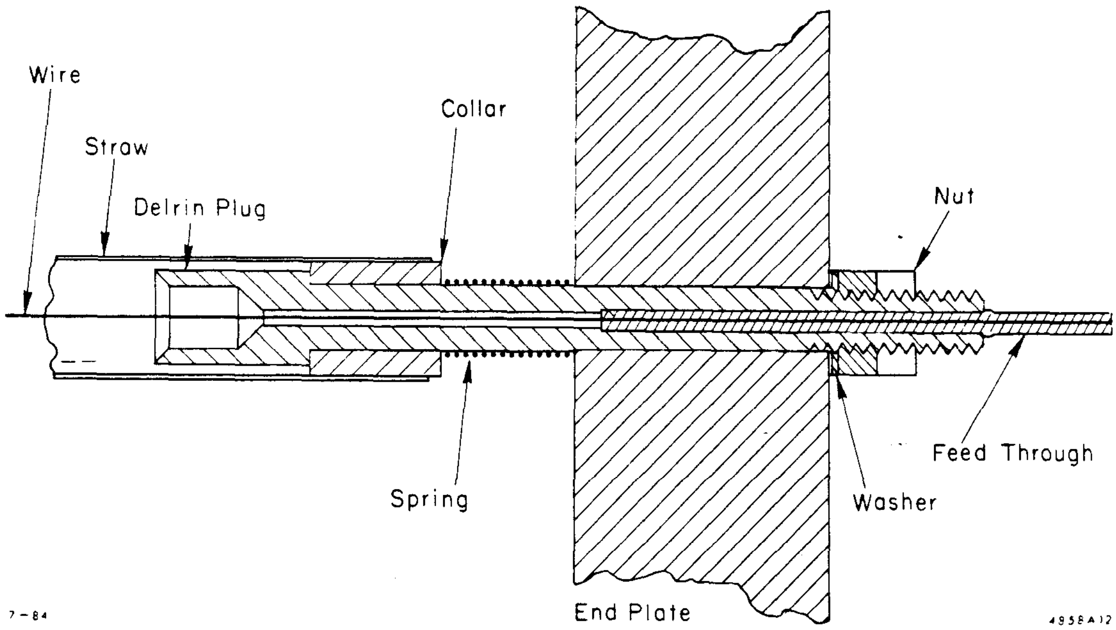

Wire
Straw
Delrin Plug
Collar
Nut
Spring
Feed Through
Washer
End Plate
7-84
4958A12

Fig. 4

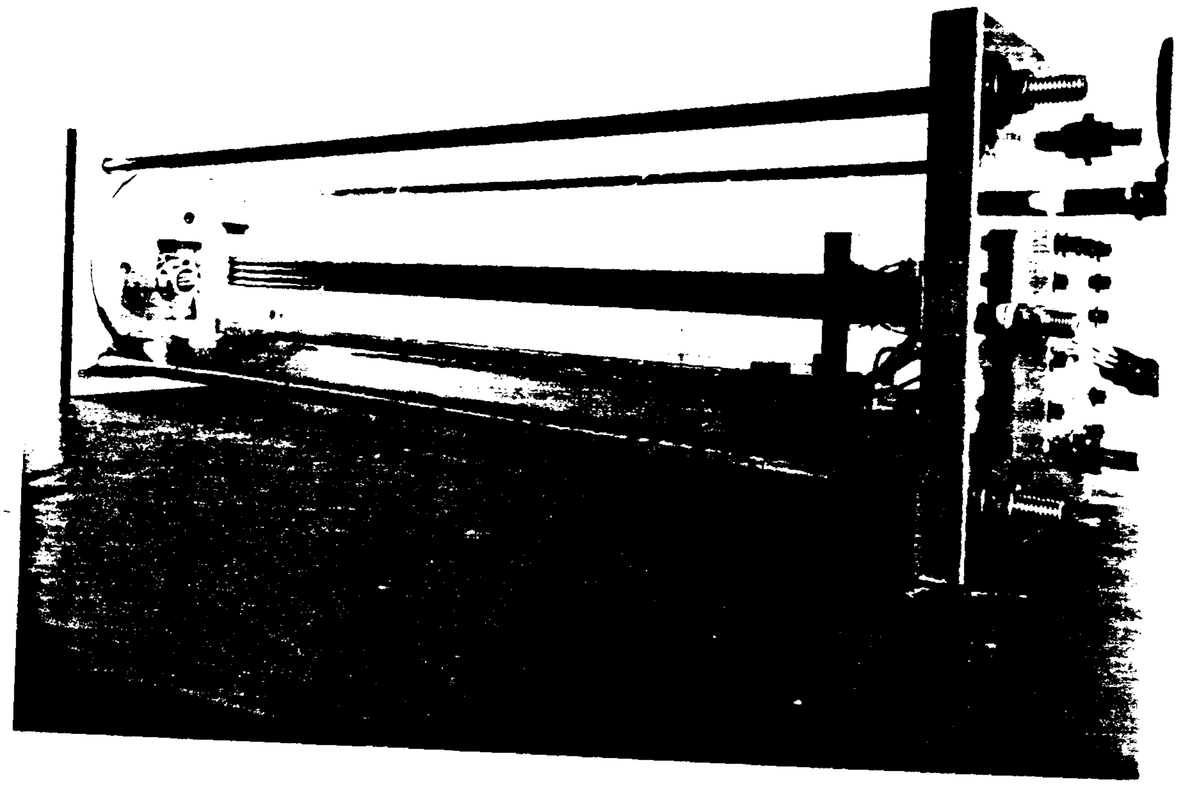
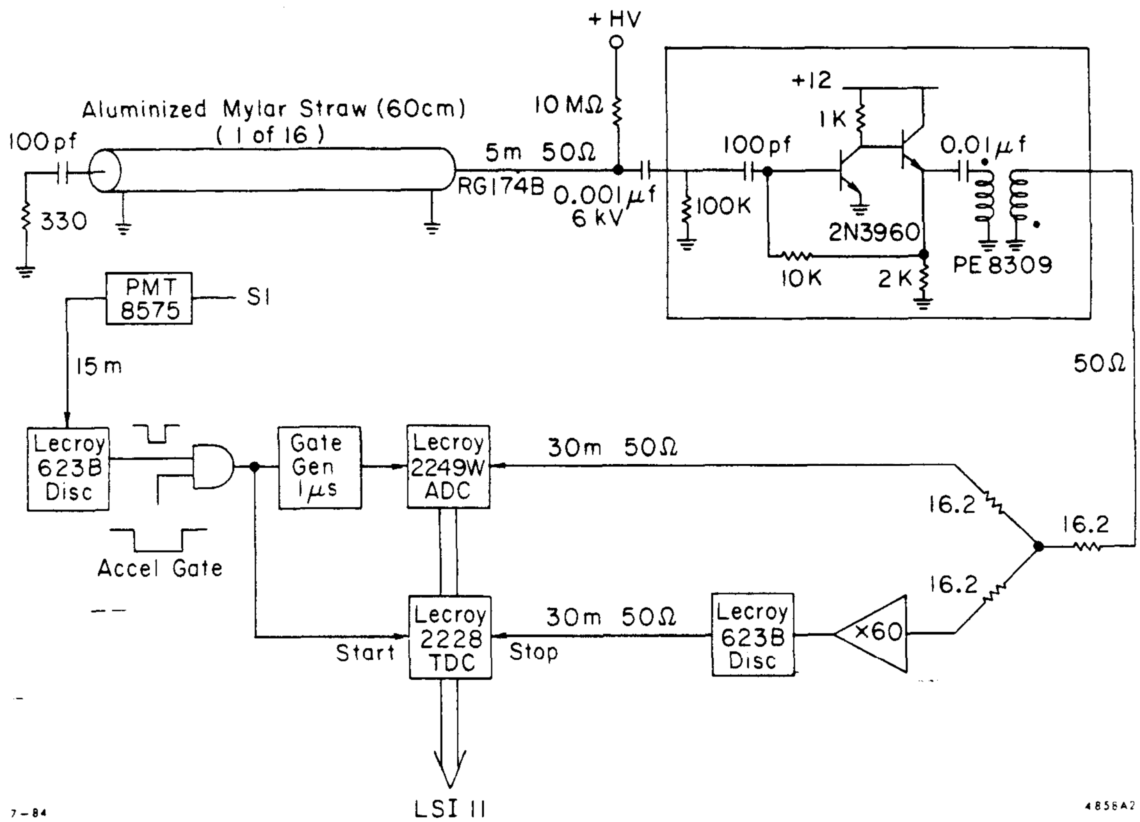
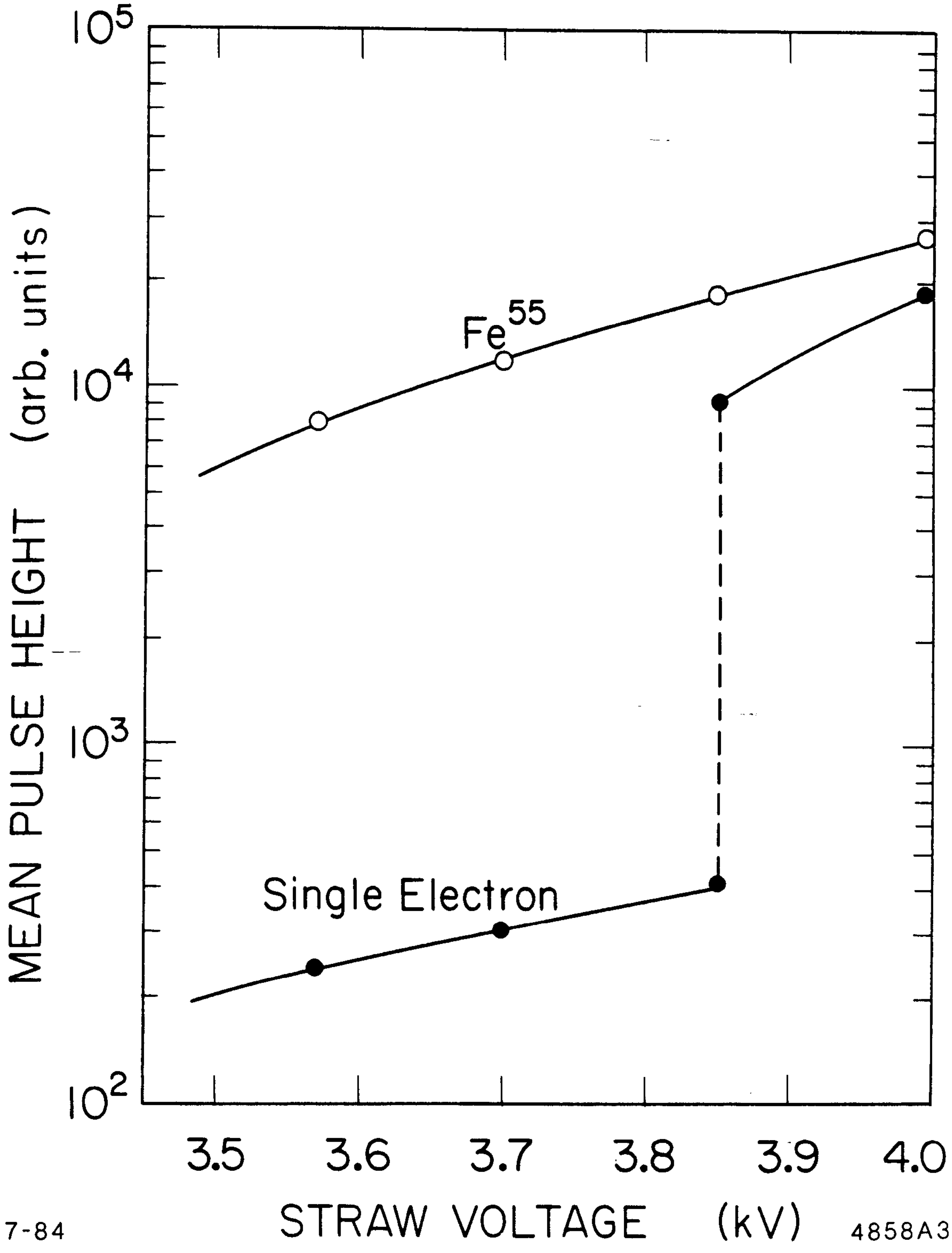


Fig. 5



+HV
Aluminized Mylar Straw (60cm)
(1 of 16)
100pf
330
10 MΩ
5m 50Ω
RG174B
0.001μf
6 kV
+12
1K
100pf
0.01μf
100K
2N3960
10K
2K
PE 8309
PMT
8575
S1
15m
50Ω
Lecroy
623B
Disc
Gate
Gen
1μs
Lecroy
2249W
ADC
30m 50Ω
16.2
16.2
16.2
Accel Gate
Lecroy
2228
TDC
Start
Stop
30m 50Ω
Lecroy
623B
Disc
×60
LSI 11
7-84
4858A2

Fig. 6



10^5
10^4
10^3
10^2
MEAN PULSE HEIGHT (arb. units)
Fe^{55}
Single Electron
3.5
3.6
3.7
3.8
3.9
4.0
STRAW VOLTAGE (kV)
7-84
4858A3

Fig. 7

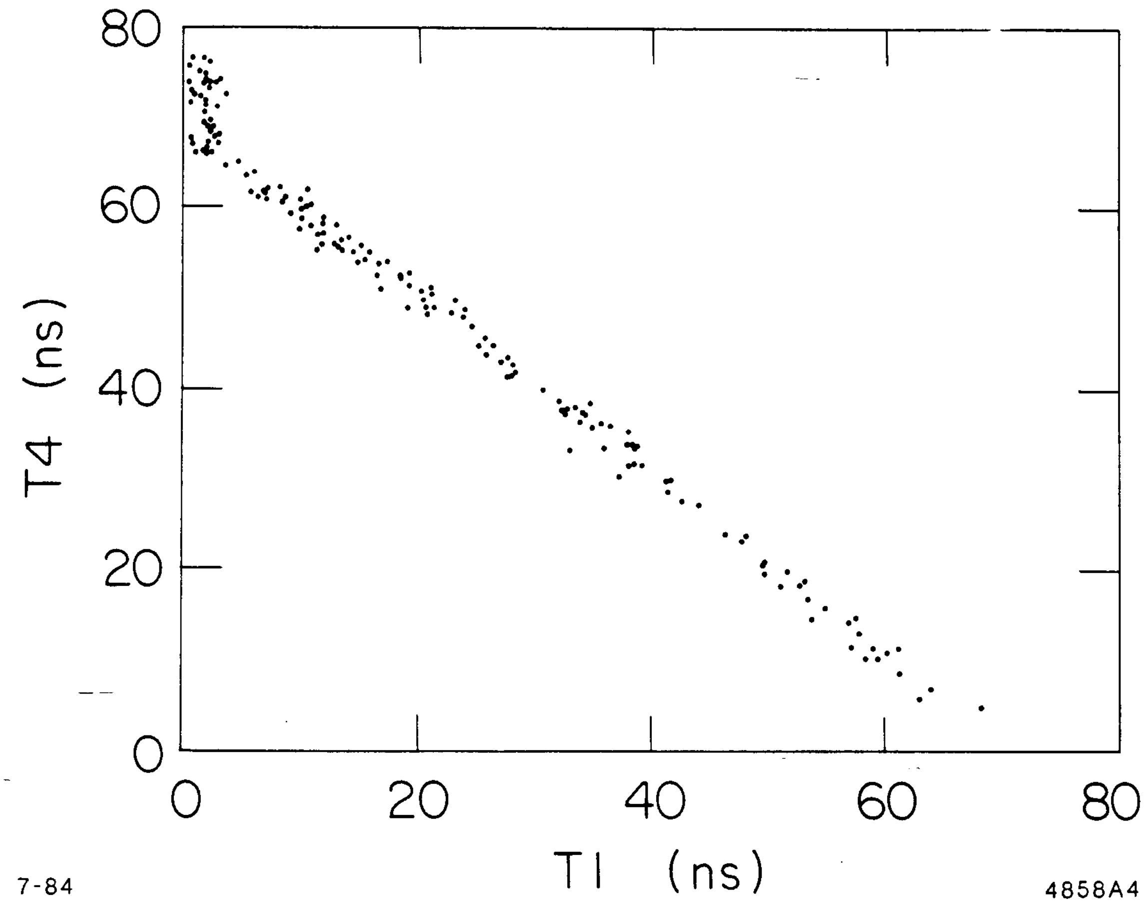


Fig. 8

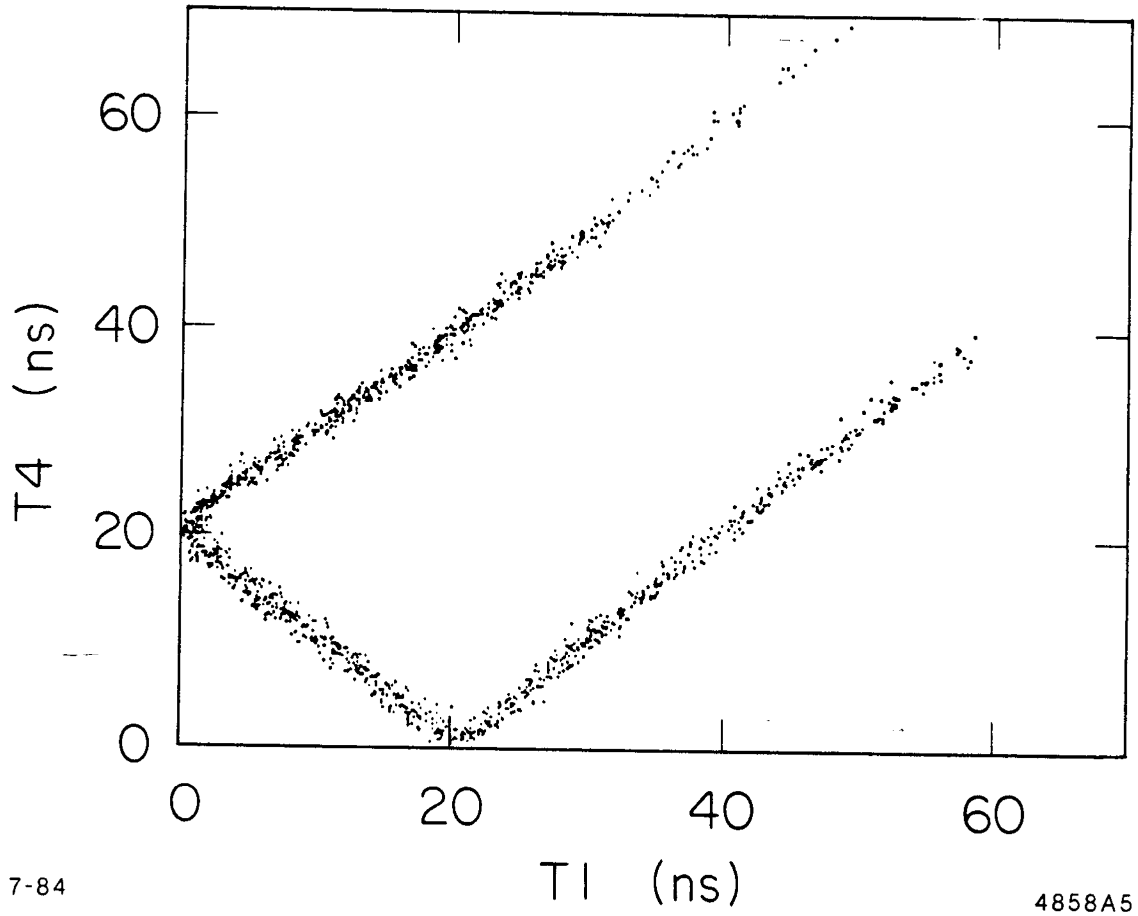


Fig. 9

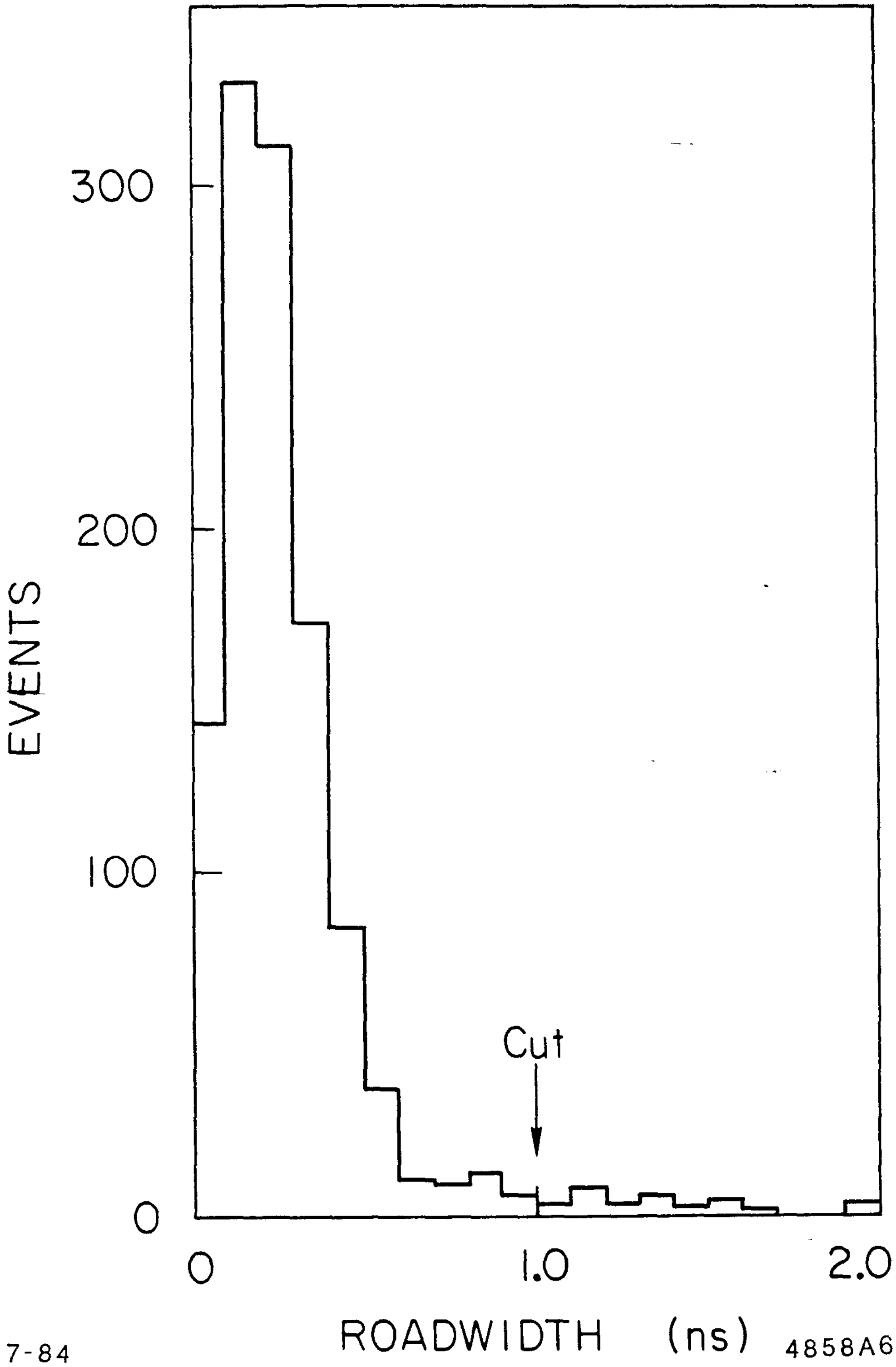


Fig. 10

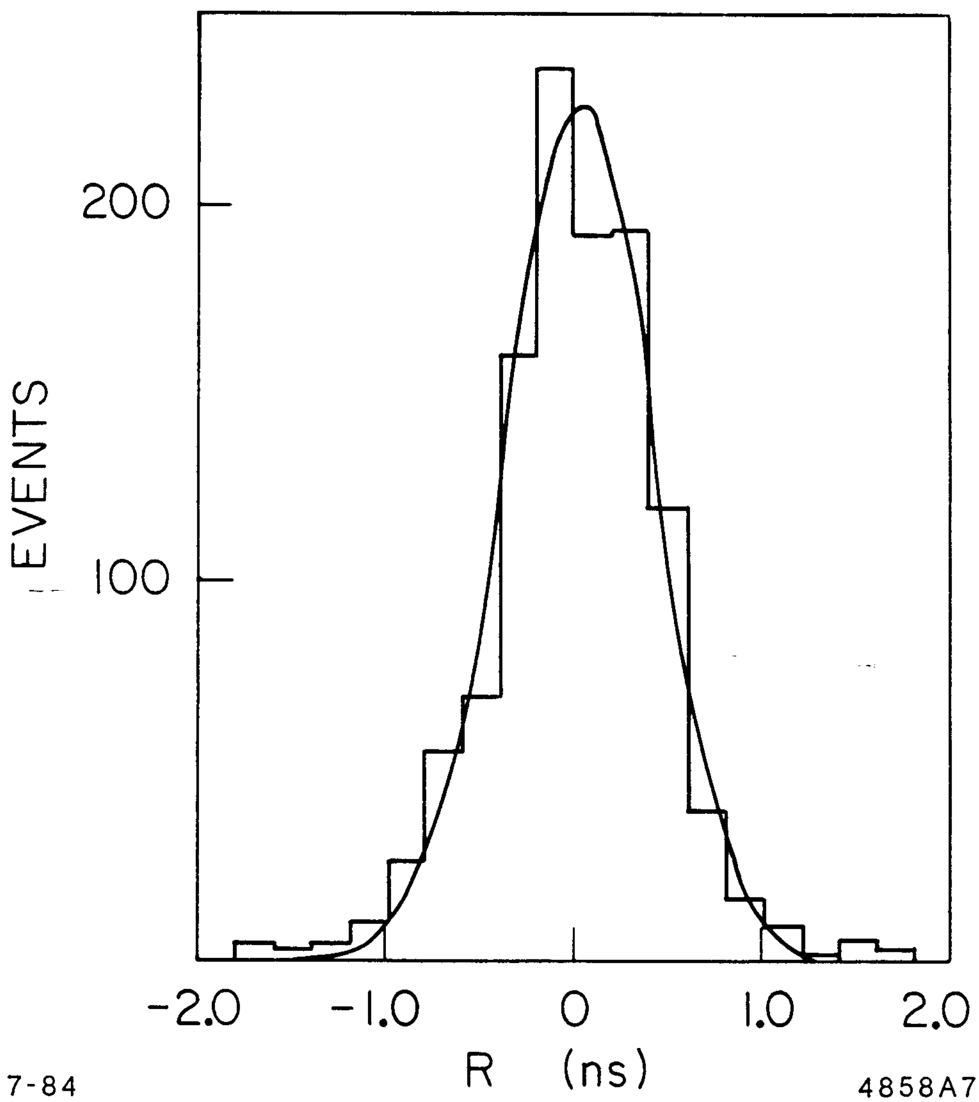
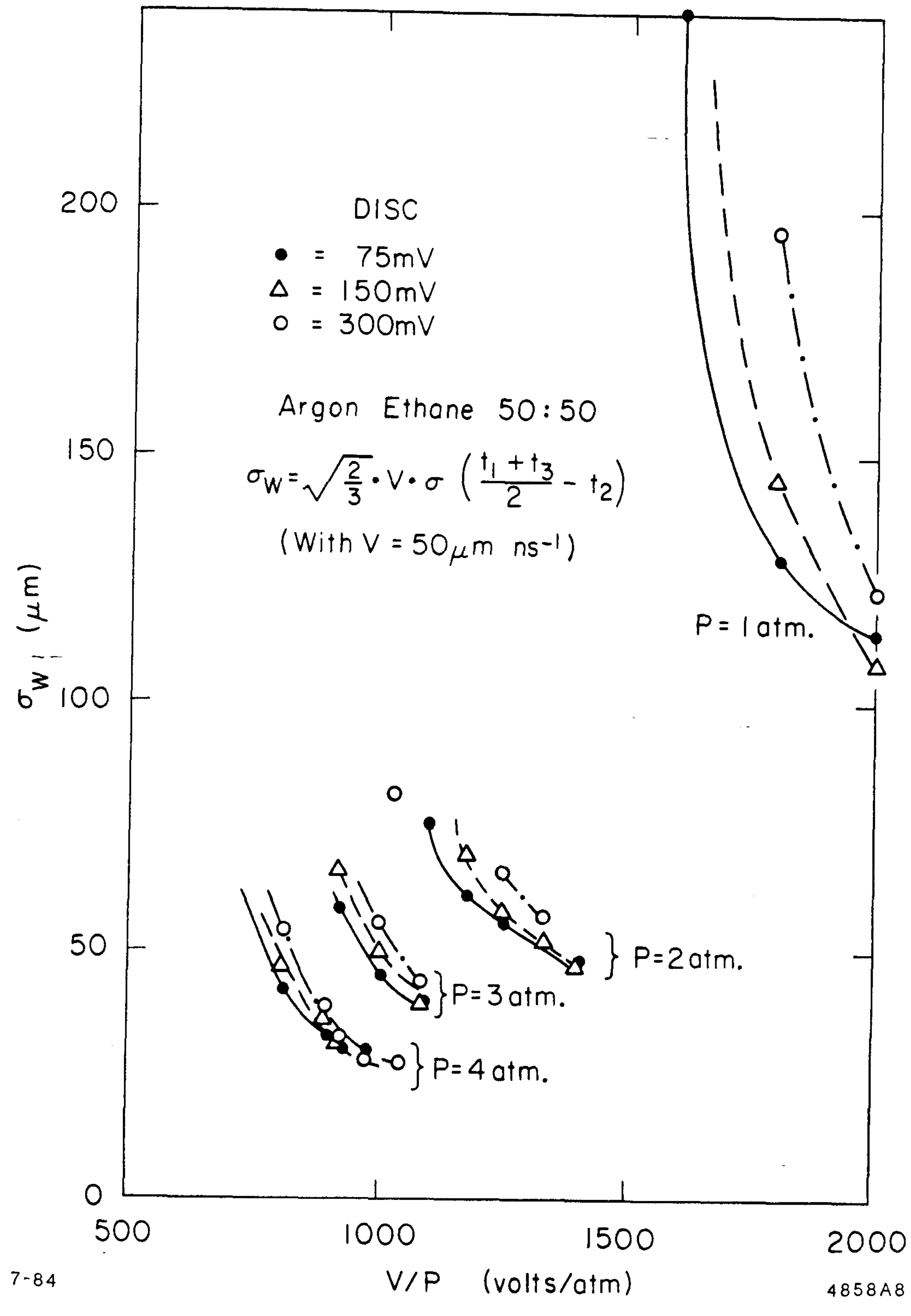
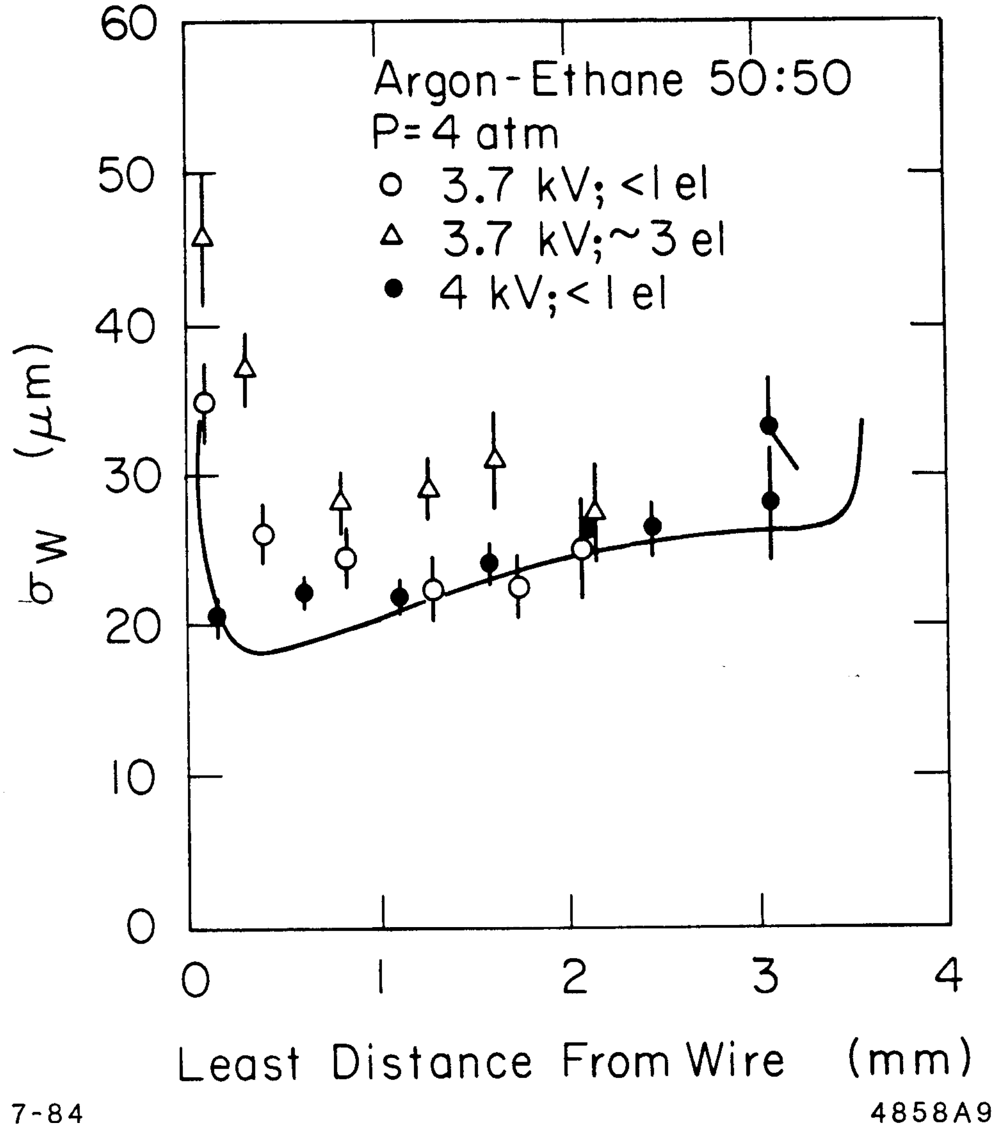


Fig. 11



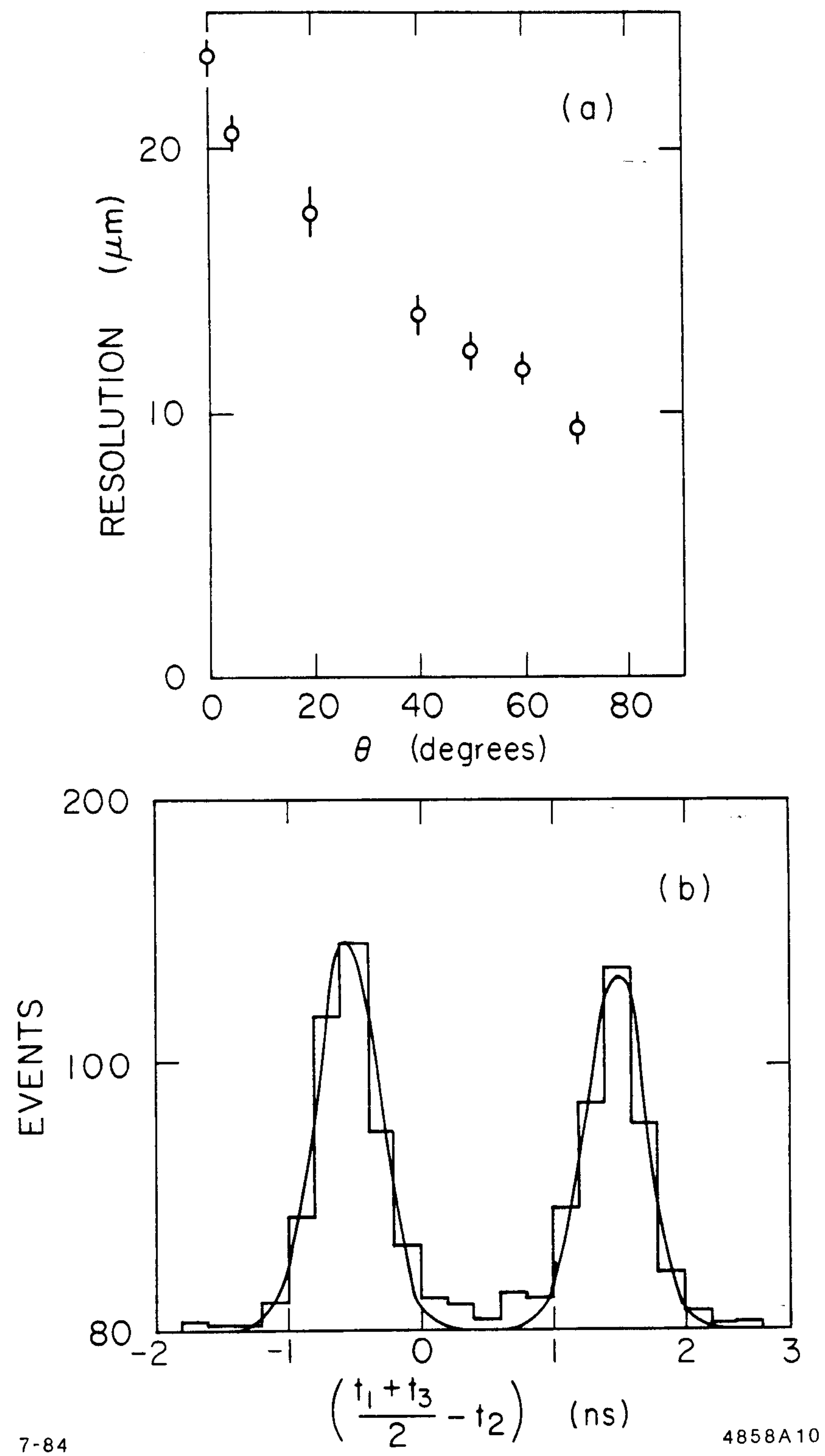
DISC
● = 75mV
Δ = 150mV
○ = 300mV
Argon Ethane 50:50
$\sigma_W = \sqrt{\frac{2}{3}} \cdot V \cdot \sigma \left(\frac{t_1 + t_3}{2} - t_2 \right)$
(With V = 50μm ns^{-1})
P = 1 atm.
P=2 atm.
P=3 atm.
P=4 atm.
σ_W (μm)
0
50
100
150
200
500
1000
1500
2000
V/P (volts/atm)
7-84
4858A8

Fig. 12



Argon-Ethane 50:50
P=4 atm
o 3.7 kV; <1 el
Δ 3.7 kV; ~3 el
● 4 kV; <1 el
60
50
40
30
20
10
0
σW (μm)
0
1
2
3
4
Least Distance From Wire (mm)
7-84
4858A9

Fig. 13



(a)
RESOLUTION (μm)
20
10
0
0
20
40
60
80
θ (degrees)
(b)
EVENTS
200
100
80
-2
-1
0
1
2
3
$\left(\frac{t_1+t_3}{2}-t_2\right)$ (ns)
7-84
4858A10

Fig. 14

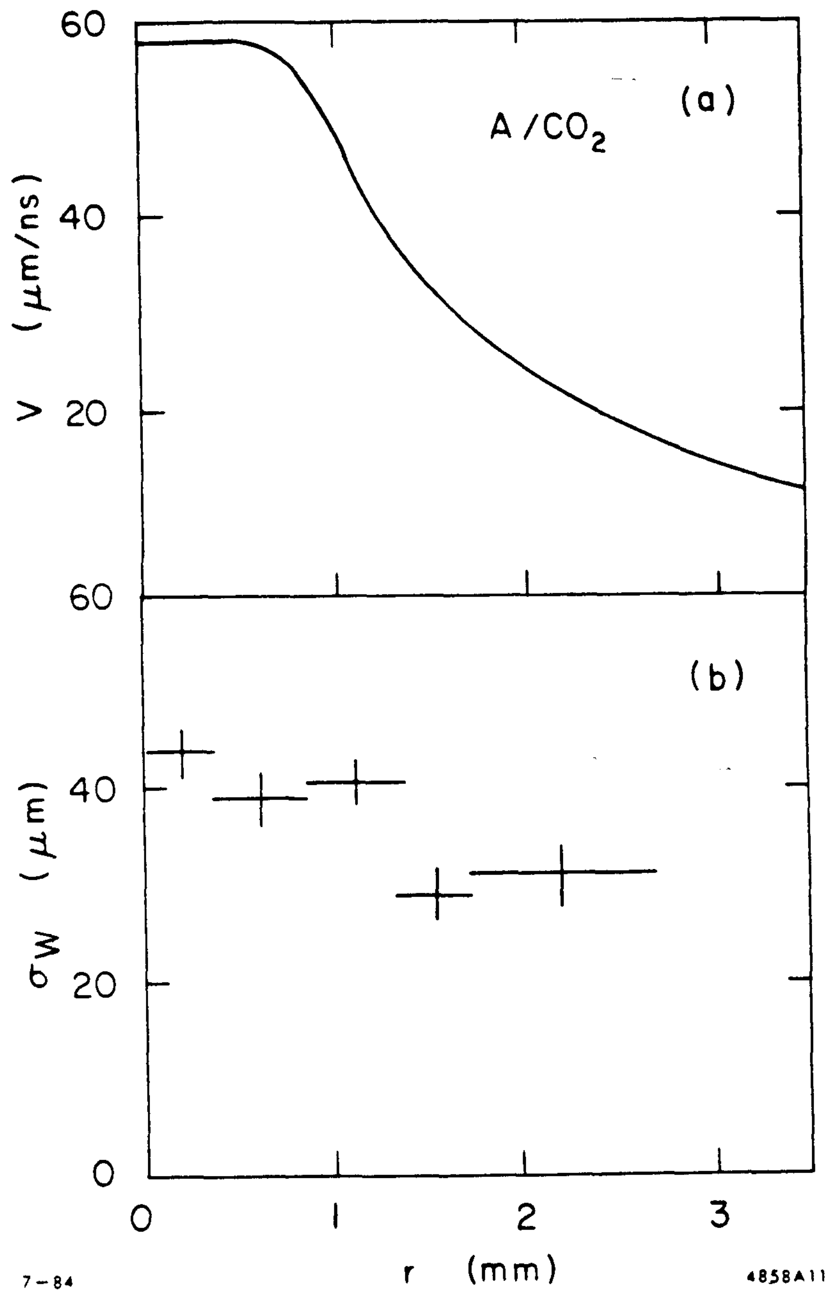


Fig. 15