dE/dx PROTOTYPE TEST*

J. Va'vra
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305
and
D. Rust
Indiana University
Bloomington, Indiana 47405

Abstract

A small prototype of a multiwire dE/dx detector was tested in SLAC's test beam. The basic concept of the detector was similar to the JADE drift cell design. The purpose of the test was to decide on some design parameters for a full size prototype, which is now in construction.

Introduction

Our motivation was to concentrate on the particle identification below 4 GeV/c which is about the limit of most of the particle distributions at PEP energies. In particular, we wanted to explore the possibility of identifying particles using a dE/dx technique in the HRS magnet. This technique was in a competition, with Cerenkov counters, proposed by the Michigan group.[1]

The available space allowed us to use only about 70 cm of active length. Our test chamber reported in this paper had 47 samples, each 1.5 cm long. This would allow a reasonable π/e identification below 4 GeV/c, π/p identification below 1.2 GeV/c and above 3 GeV/c, π/k identification below 800 MeV/c, if we would operate at atmospheric pressure. Although some of these regions can be covered by TOF and shower counter techniques, obviously not all particles could be identified by a single device in a multi-prong environment.

The type of chamber we decided to investigate resembles the JADE type of detector.[2] This type of chamber proved to be useful as a tracking device, however, there are still some questions left about its usefulness as a dE/dx device in the relativistic rise region. We felt that its concept is attractive because in addition to tracking and dE/dx measurement, it has features which limit the number of wires required and it could perform well in a high multiplicity environment.

This project had three stages. In the first stage we investigated the properties of several gases in a single sample test chamber,[3] in the second stage we tested the chamber which had full size in the x-y plane and only 10 cm long in the z-direction (most of the data reported in this paper comes from this test), and finally, we constructed a full size chamber, which is now being tested.

Description of the Prototype

The basic dimensions of the test cell are shown in Fig. 1. The active length of the wires was only 10 cm (z-direction in conventional storage ring sense). Each sample length along the track was 1.5 cm, and there were 47 samples in total. To limit cross-talk from one sense wire to its neighbor we placed field wires in between. Figures 2 and 3 show two voltage configurations we tested, one for negative and the second for positive voltage. The advantage of the positive voltage configuration is that it eliminates the need for strips (or wires) on the cathode sides. We found experimentally that it was necessary to implement a lot of AC ground (capacitors) in the wiring of the chamber. For instance, the field wire bus had to be connected to ground via three 6 kV, 4.7 nf capacitors (see Fig. 2). By removing these capacitors we observed a degradation of the pulse height resolution. The resistor chain was made using a series of 270 kΩ, 5% resistors.

The electronics used in these tests was simple. Each sense wire was connected to the LeCroy TRA 1000 amplifier (with FET in front) operating as a charge integrator with ~20 μsec RC delay constant. The resulting pulse was sampled by a 70 ns gate and digitized by LRS 2249 W ADC. The sampling gate arrived about 2 μsec after the avalanche occurred.

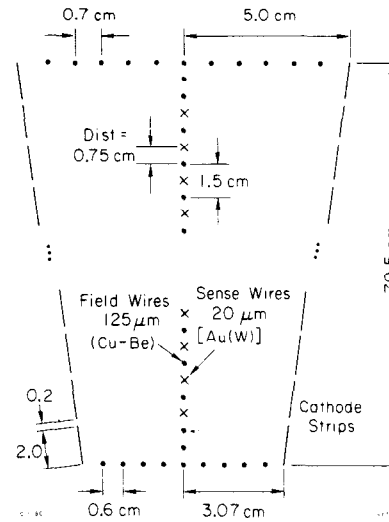The chamber was operated always at atmospheric pressure during these tests.
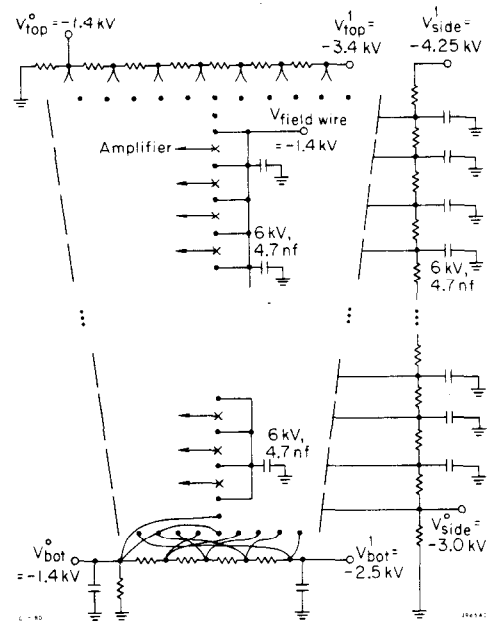

Fig. 1. Dimensions of Test Chamber.

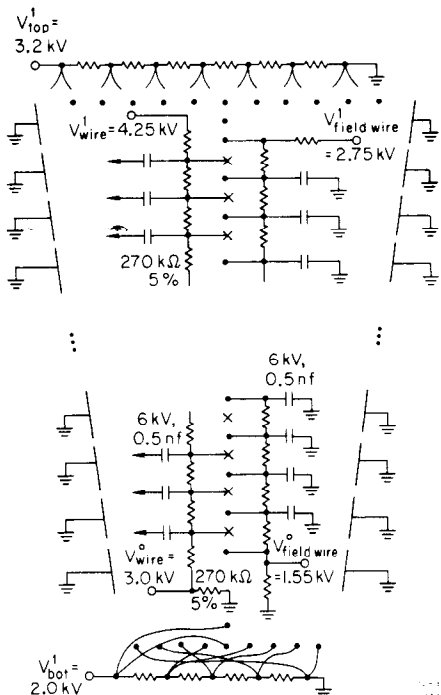Fig. 2. Negative Voltage Configuration.

Fig. 3. Positive Voltage Configuration.

Description of the Test Set-Up

The test was performed in SLAC Beam Line #6. The data were taken at 4 GeV/c by alternating between pion and electron beams. At this momentum one expects the relativistic rise difference to be about 26% in 90% Argon + 10% CH_4 gas. The selection of a particle was done using a differential Čerenkov counter and by the insertion of a lead sheet to suppress the electron background in case of the pion beam. The beam size was about 5 mm FWHM. Two small counters in front and behind insured that the beam passed through the chamber. The suppression of events with two or more particles per SLAC pulse was done off-line by recording doubles in a pile-up gate. The data were logged on tape using an LSI-11 data acquisition system. Each run lasted about 30-45 minutes. The pedestals were monitored before and after each pair of measurements.

Description of the Results

(a) Analysis of the data: After the pedestal subtraction the individual measured pulse heights were corrected for the cross-talk in the following way:

$$\left(\frac{dE}{dx}\Big|_i^{MEAS}\right) = \begin{pmatrix} 1 & ,-.06 & ,-.025, & -.01 & , & 0 & ,\ldots \\ -.06 & , & 1 & ,-.06 & ,-.025, & -.01 & , & 0 & ,\ldots \\ -.025, & -.06 & , & 1 & ,-.06 & ,-.025, & -.01 & , & 0 & ,\ldots \\ -.01 & ,-.025, & -.06 & , & 1 & ,-.06 & ,-.025, & -.01, & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{pmatrix}$$
$$\underbrace{}_{A}$$
$$\times \left(\frac{dE}{dx}\Big|_i^{TRUE}\right) . \qquad (1)$$

The corrected pulse heights were then obtained from:

$$\frac{dE}{dx}\Big|^{TRUE} = A^{-1} \frac{dE}{dx}\Big|^{MEAS} . \qquad (2)$$

This correction increased the measured pulse heights by about 20-30% on the average. We found that it was useful to do this correction, because it improved the π/e separation at 4 GeV/c by about 0.2 sigma. The next step was to adjust the relative gain variations of individual wires using runs with pions. The truncated mean distributions were fitted with a Gaussian curve. Figures 6-9 show examples of those fits.

(b) Dependence on number of rejected samples: Figure 4 shows π/e separation as a function of this dependence. We have rejected 25% of the largest samples in the rest of the analysis.
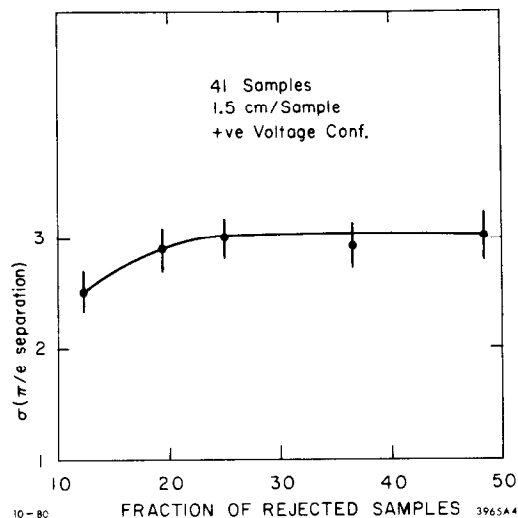

Fig. 4. Dependence on Number of Rejected Samples.

(c) Dependence on number of samples: We show this function in Fig. 5. To determine this dependence we selected a section of the chamber and kept 25% rejection of largest values a fixed number. The fit to our data indicates $n^{0.44\pm0.01}$ dependence which agrees with Walenta's[4] measurement, who also used a truncated mean technique. W. W. M. Allison[5] quotes an $n^{-0.46}$ dependence, if a maximum likelihood method is used.
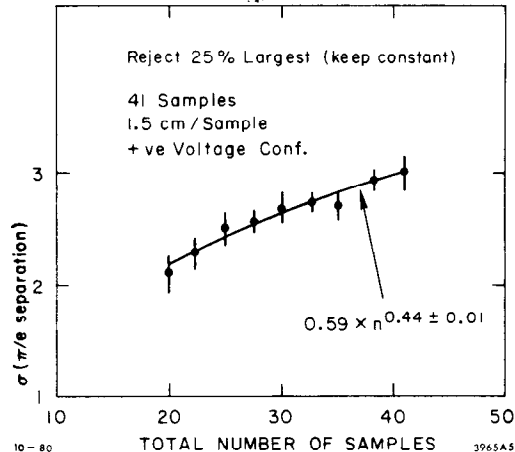

Fig. 5. Dependence on Total Number of Samples.

(d) Dependence on voltage configuration: Figures 6 and 9 show data from the negative and positive voltage configurations (see Figs. 2 and 3 for explanation). Since we see no dependence on this variable, we conclude that, we have no dependence on the external wiring of the chamber.

(e) Dependence on gas: We have tested three gases: 90% Ar + 10% CH_4, 90% Ar + 9% CO_2 + 1% CH_4 and 50% Ar + 50% C_3H_8. Figures 6-9 show individual distributions of the truncated mean for pions and electrons at 4 GeV/c. Figure 10 summarizes all results as a function of gas type. We see that all three gases produce the same π/e separation, although individual pulse height resolution is improved in the denser gases, the difference in ionization between pions and electrons is reduced by the density effect and the separation remains the same.
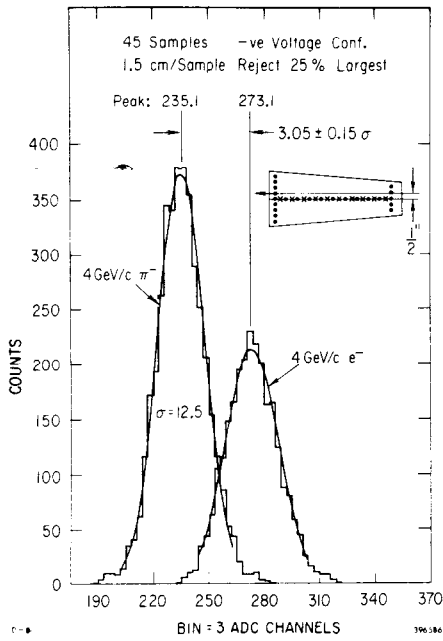
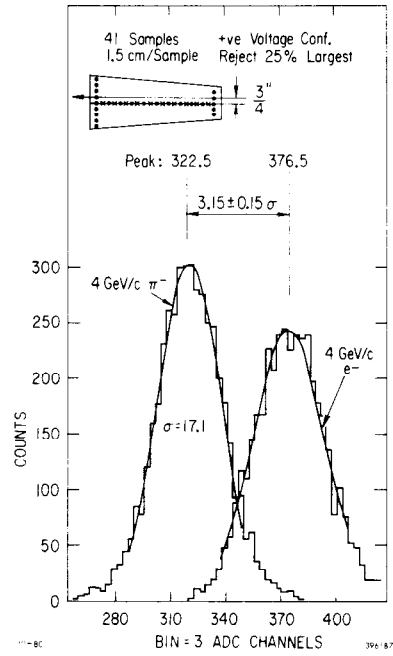Fig. 6. Truncated Mean Distribution in 90% Ar + 90% CO$_2$ + 1% CH$_4$.

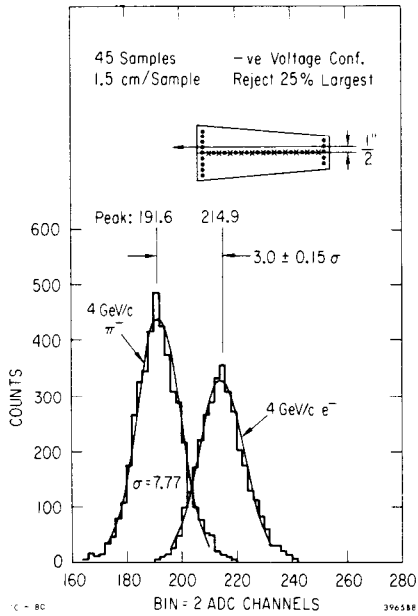Fig. 7. Truncated Mean Distribution in 90% Ar + 10% CH$_4$.

Fig. 8. Truncated Mean Distribution in 50% Ar + 50% C$_3$H$_8$.
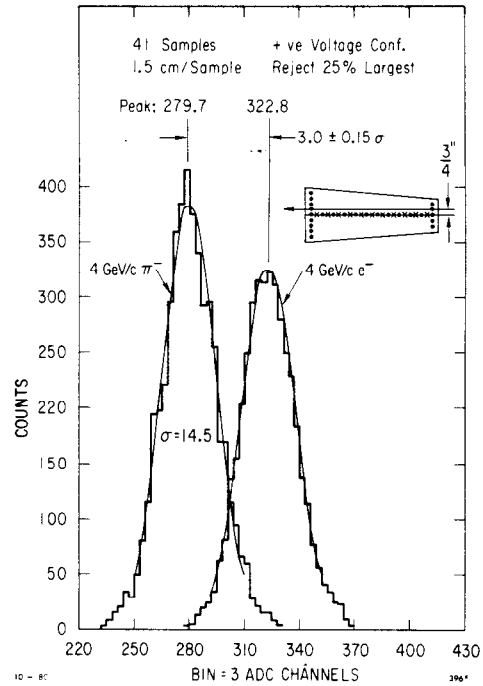

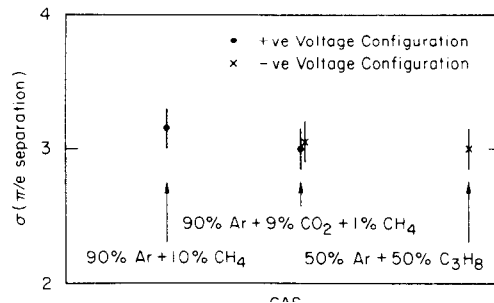Fig. 9. Truncated Mean Distribution in 90% Ar + 90% CO$_2$ + 1% CH$_4$.

Fig. 10. π/e Separation as a Function of Gas.

Allison[5] quotes a formula describing the pulse height resolution in any gas

$$FWHM(n)/PEAK = 81n^{-0.46}(\xi/I)^{-0.32} \qquad (3)$$

where I is mean ionization potential, n is number of samples and ξ in electron volts is given by[6] 1.53×10^5 (Z/A)ρt, where ρt is in g/cm^2, Z atomic number and A atomic weight. If we use our results in Figs. 6-9, we produce the following comparison with the gas

formula (see Table I). We see that all our results yield better resolutions compared to the formula. The explanation is in the fact that we operated our chamber at a gain of 2-3 × 10^4. Figure 11 shows our previous measurement[3] with a single sample cell. We see that at this gain we already improve the resolution and reduce the relativistic rise due to the onset of saturation. We estimate that operating at a gain 10^4 or less we would agree with a formula (3) and we could improve our π/e separation at 4 GeV/c by about 0.5 sigma.

TABLE I

Gas	ξ/I (1.5 cm)	(FWHM(1)/PEAK)$_{MEAS}$	(FWHM(1)/PEAK)$_{FORMULA(3)}$
90% Ar + 10% CH_4	0.92	69 ± 5%	83%
90% Ar + 9% CO_2 + 1% CH_4	0.95	72 ± 5%	82%
50% Ar + 50% C_3H_8	1.76	55 ± 5%	67%
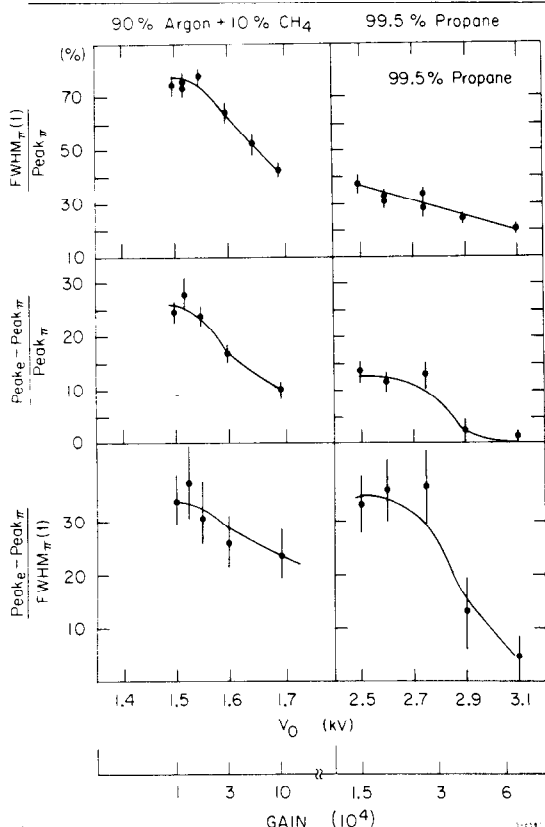
Fig. 11. Results from a Single Sample Tests[3] (Sample Length 2.2 cm).

Fig. 12. Dependence on Number of Bits Used.

TABLE II

Wire	Measurement	Computer Simulation
$\emptyset$	-100%	-100%
1st neighbor	+(6 ± 1)%	+5.6%
2nd neighbor	+(2.5 ± 0.5)%	+1.5%
3rd neighbor	+(1.0 ± 0.5)%	+0.4%

(f) Dependence on number of bits in ADC: We have used an LRS 2249W ADC, which has 11 bits. This allowed us to investigate the π/e separation as a function of number of bits used. Figures 12(a) and 12(b) indicate that we could drop one most significant and two least significant bits and still produce the same results. The use of 6 bits only would reduce the π/e separation at 4 GeV/c by about 0.15 sigma. This means cheap fast ADC's may be used in dE/dx measurement.

(g) Cross-talk measurement: It is well known that the positive drifting ions will produce the positive pulses on the neighboring sense wires. These pulses have the same time structure as the primary negative pulse on the sense wire which had avalanche. Table II summarizes our measurement with this chamber. We have reproduced the same numbers in both voltage configurations. It is interesting to note that one can estimate these cross-talk values using an electrostatic program[7] by applying a certain voltage to a given sense wire and observing the relative changes of the charges on neighboring wires.
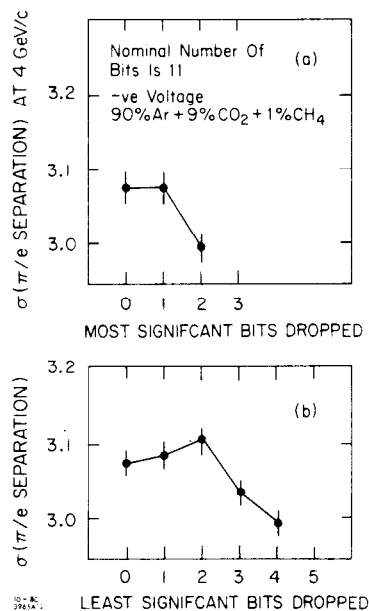
(h) Gain calibration and allowed mechanical tolerances: We have measured the total gain in the chamber as a function of various voltage settings on the field wires and cathode sides. For each voltage setting we have run the electrostatic program and calculated the electric gradient on the surface of the sense wire in the middle of the chamber. Figure 13 shows the summary of this calibration. We could then simulate an imperfection in the chamber and calculate a change in the electric gradient of this wire. Figure 14 shows examples of simulated imperfections. We conclude that if one wants to keep the gain variations to 1% one should keep the cathode flatness to about 0.1 mm. This contrasts with a requirement on the position of the sense wire itself. Standard imperfections in wire locations have no effect on the pulse height measurement.
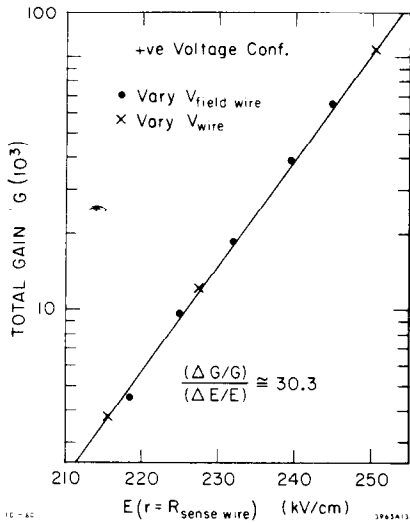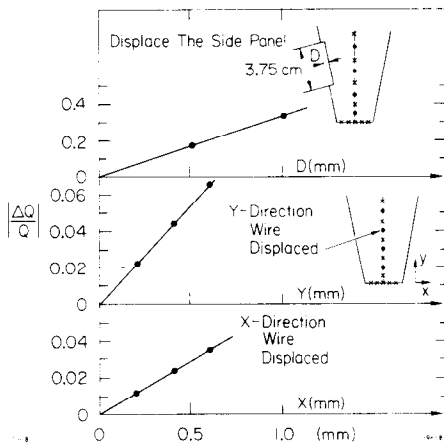
Fig. 13. Gain Calibration.

Fig. 14. Effect of Mechanical Tolerances on Gain.

(i) Systematic problems: We would like to mention one possible problem with this type of chamber. One can select voltages on the chamber which can cause low (or even wrong sign) drift gradients very near the field wires. Figure 15 shows the drift gradient 1 mm away from the field wire for the negative voltage configuration as a function of the field wire voltage and the distance between the sense and field wires. Negative gradient means that electrons will not drift toward the sense wire. This effect is rather sensitively dependent on the particular combination of voltages. If one tries to solve the problem by increasing the field wire voltage, one reduces the average drift gradient in the cell. These pockets of low drift gradient invite problems with attachment. Figure 16 shows that one can produce a dip in the pulse height distribution as the particles travel through the wire plane.

Conclusion

We have made some systematic studies with a small dE/dx chamber. The pulse height resolution, after correction for the gain, is consistent with Allison's formula.[3]

Acknowledgements

We would like to thank Dr. L. Keller, T. Pulliam, and H. A. Weidner for their interest and help during this project. We appreciate the interest and help of several people from the Mark III group, especially Kevin Einsweiler, who was very helpful during the initial period.
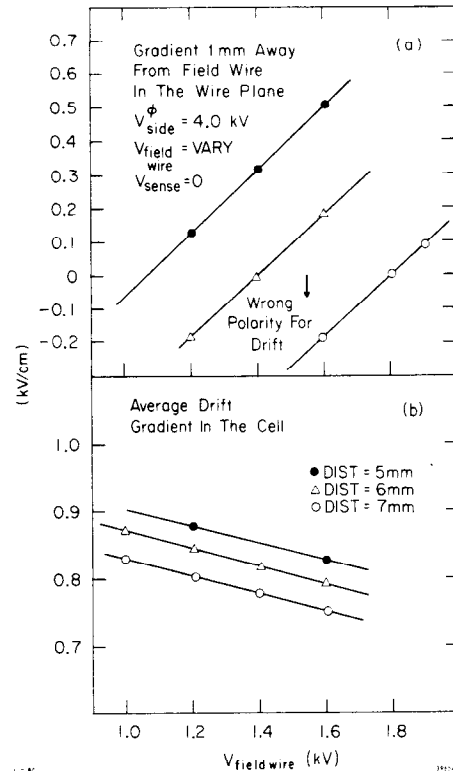

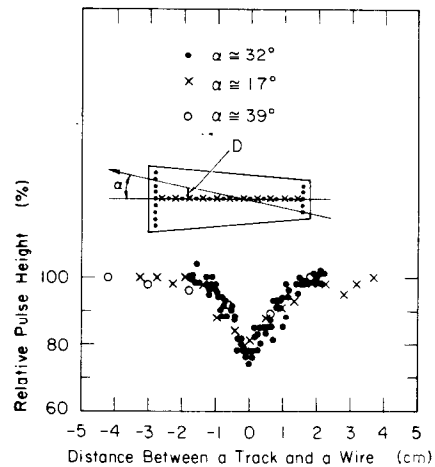Fig. 15. Computer Simulation of the Cell.

Fig. 16. Relative Pulse Height as a
Function of Distance Between
a Track and a Wire.

References

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