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# SDC
# SOLENOIDAL DETECTOR NOTES

## DRIFT TUBE SYSTEMATICS

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# Drift Tube Systematics

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All of the information which we utilize from an individual drift tube is contained in the times of the transitions of its discriminator output. The expected time of a transition is systematically related to the time and position of the passage of a charged particle through the tube. The actual time of the transition will differ from the expected time because of the statistical fluctuations in ion production and diffusion. For our present purposes we will ignore all such statistical effects and consider the systematics of the expected time of the transition.

We relate everything to $t_0$, the time of passage of the ionizing particle. At $t_0$ a line of electrons are released along the particle path. Each electron drifts toward the anode under the influence of the electric fields it encounters. They arrive at the avalanche region at various times, and each produces an avalanche and induces a signal on the anode wire. That signal is amplified. A discriminator observes the amplified signal. When the signal passes a set threshold level it produces a transition in the discriminator output. That transition is the one of interest.

In the usual circumstances the discriminator setting and the gas and amplifier gains are such that only the earliest arriving electrons play a role. The transition time, $t_T$, is therefore given by

$$t_T = t_0 + t_d + t_e, \tag{1}$$

where $t_d$ is the drift time and $t_e$ is the electronics delay. What will interest us most is the relation of the least drift time to both the track geometry and the drift tube configuration.

Figure 1 shows, as an example, the electric field lines and isochrones for the type of drift tube used in D0. This is a computer generated figure produced by Tianchi Zhao using the CERN program "Garfield". The coordinate parallel to the wire has no effect and is suppressed in these descriptions. We presume that the magnetic fields will be small and their influence negligible. In that case the electron drift is always in the direction of the electric field. An isochrone is a locus of points having equal drift times to the anode. Also shown in Figure 1 is a representative particle track and the coordinates, x and $\Theta$, used to describe it.

Because the isochrones are always concave toward the anode the least drift time for the electrons released along the particle path is the drift time of the isochrone to which the track is tangent. Although we will not expand on the statistical properties in this paper,

it is well to note that the tangency of the track to the isochrone insures that there will be an abundance of electrons closely competing to be first, and that this situation will be very much the same independent of $\Theta$ over a wide range of $\Theta$.

We take the drift time of the first electrons to arrive as $t_d$, and the coordinate of the intercept of the track with the y=0 plane as x. From Figure 1 we can find $t_d$ as a function of x and $\Theta$. Figure 2 shows (for the D0 tube) $t_d$ as a function of x with $\Theta$ as a parameter. Since $t_d$ is an even function of both x and $\Theta$ we need to examine only the first quadrant. With that constraint $t_d$ is nearly linear in x, and more generally

$$t_d = a|x| + F(x, \Theta) \tag{2}$$

Because our ultimate objective will be to determine x from various observations of $t_T$, it will be useful to express Equation (2) in inverted form:

$$|x| = A + vt_d + G(x, \Theta) \tag{3}$$

Here $G(x,\Theta)$ represents the residual, the departure from a linear relation. Figure 3 shows $G(x,\Theta)$ as a function of x with $\Theta$ as a parameter. Here we have chosen A and v to make $G(x,0) \simeq 0$. The standard procedure is to choose A and v so that the rms value of $G(x,\Theta)$ is minimized over some working region in x and $\Theta$. In a practical application in which the tracks of interest had a restricted range in x and $\Theta$, A and v would be chosen to minimize the rms value over that range. Note that the larger the central value of $\Theta$ the poorer the fit will be.

Over a large, but sharply bounded region in x and $\Theta$, the $\Theta$ dependence is itself systematic. This $\Theta$ dependence may be expressed as $f(\Theta)$. Therefore, we have

$$|x| = vt_d - f(\Theta) + H(x, \Theta), \tag{4}$$

where $H(x,\Theta)$ represents the residual. Figure 4 shows $H(x,\Theta)$ as a function of x with $\Theta$ as a parameter for the D0 cell. In this and subsequent figures $f(\Theta)$ was chosen to make $H(x,\Theta) \simeq 0$ for a large region of x.

Over a large region the rms value of $H(x,\Theta)$ is quite small, certainly very much smaller than the rms value of $G(x,\Theta)$. It behooves us, therefore, to seek a configuration of tubes and a measurement algorithm for determining x from the observed $t_T$ values such that the residuals are H rather than G. We shall presently show how this can be arranged.

Figures 3 and 4 relate to the D0 drift tubes. The corresponding figures for the original CDF tubes are 5, 6, and 7, and for an ideal drift tube, 8 and 9. For the ideal drift tube we have used the field configuration of a multisampling drift chamber ("jet chamber") and the scale has been arbitrarily chosen to coincide with the D0 and CDF scale. Clearly the D0 design was a vast improvement over the earlier CDF design. Still even the D0 design does not realize the ultimate suppression of systematic residuals.

## Seeking an Algorithm

We would like to have $H(x,\Theta)$ as our residual rather than $G(x,\Theta)$. In order to do this we must contend with the $f(\Theta)$ term. One way would be to include the $f(\Theta)$ term in the

software. This would require us to make an independent determination of $\Theta$. An easier and usually more accurate way is to combine the data from two drift tubes so the f($\Theta$) terms cancel while preserving the useful information. This relies on the fact that $\Theta$ will be the same for both tubes. Therefore it is not necessary to determine its value.

Consider the case illustrated in Figure 10 in which the particle traverses two tubes, a and b. The coordinates of the anode wires are $X_a$,$Y_a$ and $X_b$,$Y_b$ with $X_b > X_a$. The point on the track which lies on the median plane is $X_p$,$Y_p$.

From the geometry we obtain

$$X_p = X_a + x_a + h\ tan\ \Theta \tag{5}$$

$$X_p = X_b + x_b - h\ tan\ \Theta \tag{6}$$

$$X_p = \frac{X_a + X_b}{2} + \frac{x_a + x_b}{2} \tag{7}$$

For the configuration of Figure 10

$$X_p - \frac{X_a + X_b}{2} = \frac{|x_a| - |x_b|}{2} \tag{8}$$

From Equations (1) and (4) we obtain

$$|x_a| = v(t_{Ta} - t_o - t_e) + f(\Theta) + H(x_b, \Theta) \tag{9}$$

$$|x_b| = v(t_{Tb} - t_o - t_e) + f(\Theta) + H(x_b, \Theta) \tag{10}$$

Thus we have

$$\frac{|x_a| - |x_b|}{2} = \left(\frac{v}{2}\right)(t_{Ta} - t_{Tb}) + \frac{H(x_b, \Theta) - H(x_b, \Theta)}{2} \tag{11}$$

Substituting in Equation 8 we have

$$X_p - \frac{X_a + X_b}{2} = \left(\frac{v}{2}\right)(t_{Ta} - t_{Tb}) + \frac{H(x_a, \Theta) - H(x_b, \Theta)}{2} \tag{12}$$

The measure of the track coordinate $X_p$ is $\frac{X_a+X_b}{2} + (\frac{v}{2})(t_{Ta} - t_{Tb})$ and the residual in that measurment is $[H(x_a, \Theta) - H(x_b, \Theta)]/2$. Its RMS value is $\frac{1}{\sqrt{2}}$ times the RMS value $H(x, \Theta)$ which can be made very small if one chooses an appropriate tube design and the x's fall within the working region described above.

The caveat in all of this is that the tubes must be arranged in such a way that we can be sure that for any particle track of interest the presumed configuration will exist for some pair of tubes and that we can readily identify that pair.

If we had only two layers of tubes, and they were aligned, projectively, so that the tubes of one plane were offset from those in the other by half a cell width then all of the requirements would be approached, but none reached. Most tracks would traverse two

tubes. The dead spaces between cells would be a problem. The track would usually pass between the two anode wires. Some tracks, having been scattered or deflected by the magnetic field, would pass both wires on the same side. The greatest problem, however, is that many tracks would pass close to one or another of the anode wires and therefore not be in the region of small H.

All the requirements will be satisfied if there are three layers of tubes aligned projectively so that the tubes in any layer are offset from those in each of the other layers by one third of the cell spacing (Fig. 11). In this configuration a particle will generally trigger three tubes, but never less than two. Unless it forms a very large angle with respect to the projection direction, and therefore is a track of no interest, it will pass between the anode wires of the tube which gave the first pulse and that which gave the second. It will also pass between the anodes of the tube which gave the second pulse and that which gave the third. There will always be at least one candidate pair of tubes and generally two. The track may have passed close to one of the anode wires and so be outside the region of small H. That anode will give the earliest pulse so, if there are three pulses, the second and the third should be used. If there are only two pulses they will be in the good region since no plausible track can pass between cells in one layer and close to the anode in another.

We have found a means of extracting a point $X_p$,$Y_p$ which lies on the track. We can also extract $\Theta$. Consider the configuration illustrated in Figure 12 which is similar to Figure 10 except that the track does not cross between the anodes. In this example the track passes "down-x" from both anodes. "Up-x" from both is also a possible configuration.

From Equations (4) and (5) we have

$$h\ tan\ \Theta = -\frac{X_a - X_b}{2} - \frac{x_a - x_b}{2} \tag{13}$$

From the geometry, Figure 11

$$-\frac{X_a - X_b}{2} = h\ tan\ \Theta \tag{14}$$

Thus

$$h(tan\ \Theta - tan\ \Theta_0) = -\frac{x_a - x_b}{2} \tag{15}$$

Since for the example shown in Figure 11 $x_a = -|x_a|$ and $x_b = -|x_b|$ we have

$$h(tan\ \Theta - tan\ \Theta_0) = \frac{|x_a| - |x_b|}{2} \tag{16}$$

In the "up-x" configuration we would have

$$\frac{-h(tan\ \Theta - tan\ \Theta_0)}{2} = \frac{|x_a| - |x_b|}{2} \tag{17}$$

We also have

$$h|tan\ \Theta - tan_b\ \Theta_0| = \left|\frac{|x_a| - |x_b|}{2}\right| \tag{18}$$

The right-hand side of Equations (16), (17) and (18) is the same as the right-hand side of Equation (8) and thus the discussion above applies here as well.

Equation (18) is of particular interest for triggering. If the tubes are arranged as projective towers so that the line of anodes projects back to the interaction region then $tan\ \Theta - tan\ \Theta_0$ is a measure of the deviation of the track from that of a rigid particle and an upper bound on $|tan\ \Theta - tan\ \Theta_0|$ is a lower limit on the muon momentum. It is a bound which is expressed as a simple time difference which is easily measured. This has been discussed by Jay Chapman.

In forming a trigger we must again arrange things so we can be sure of obtaining valid measurements. We add to the three-layer arrangement already described another three layers with the new tubes matched one-to-one with the old to form projective towers. A traversing particle will generally trigger six tubes, two tubes in each of three towers; thus there will typically be three independent measurements of momentum. One of the three could be missing because of the dead spaces. One could be an invalid measurement in which a low momentum track mimics a high momentum one by crossing between the anode wires. A true high momentum track will always give at least two good readings which cannot be mimicked by a low momentum particle.

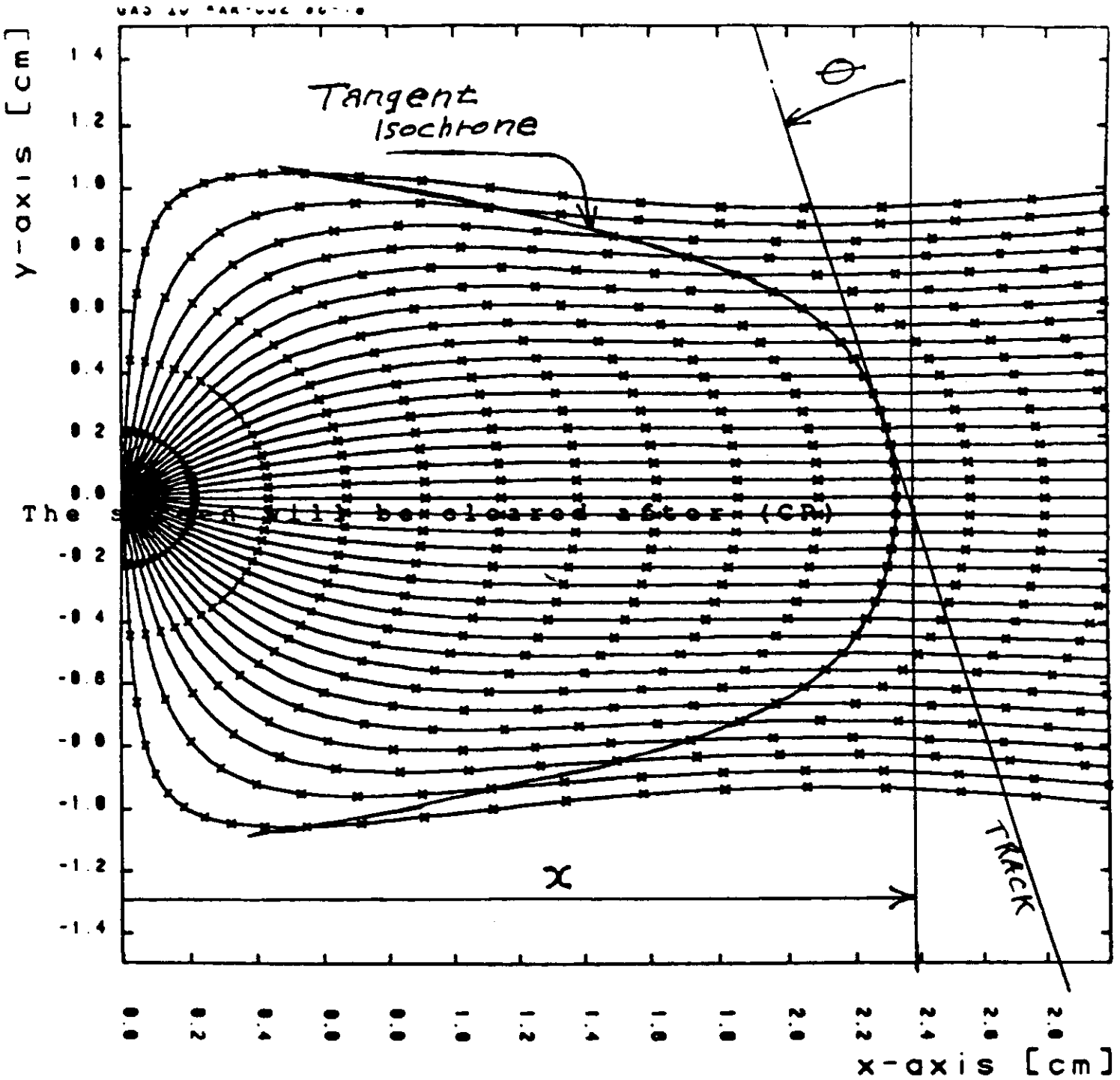


Figure 1: Field lines and isochrones of D0 drift cell and the relationship between track parameters (x,Θ) and the tangent isochrone.

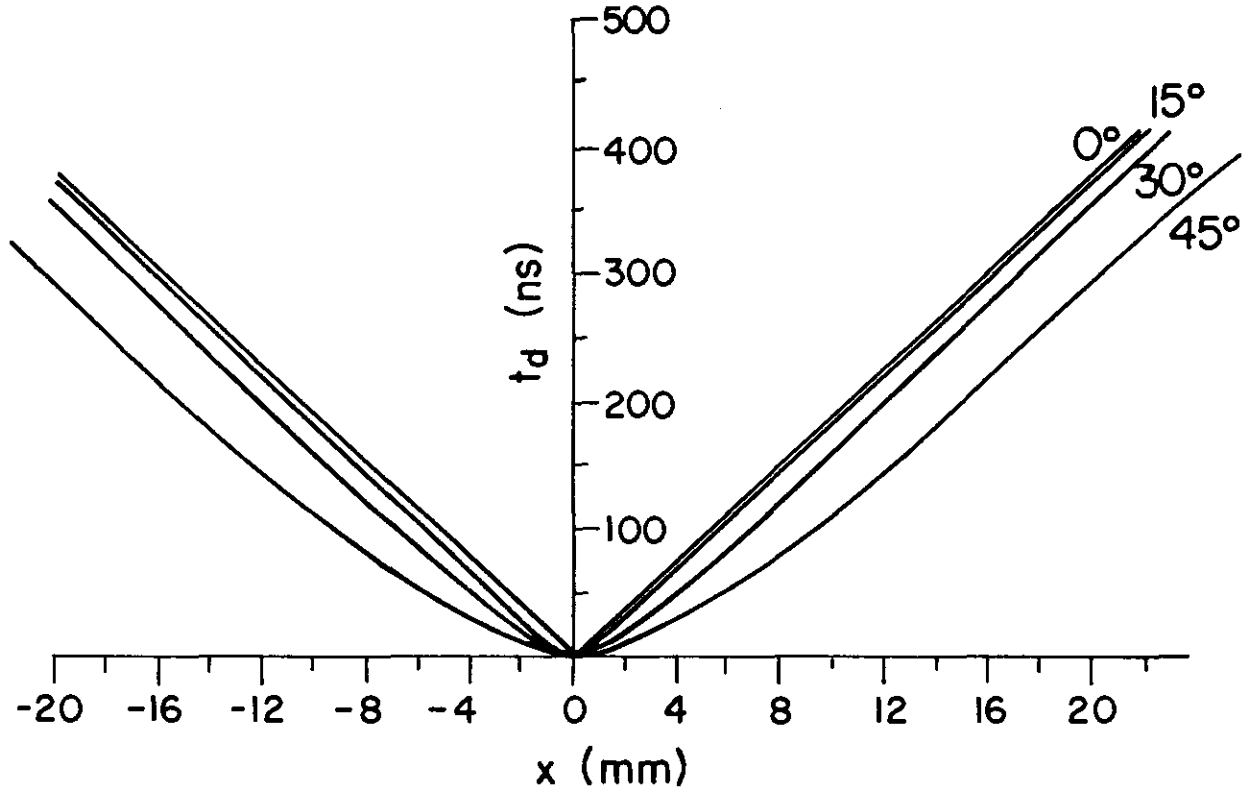


Figure 2: Drift time vs. track intercept with incident angle as a parameter (D0 field).

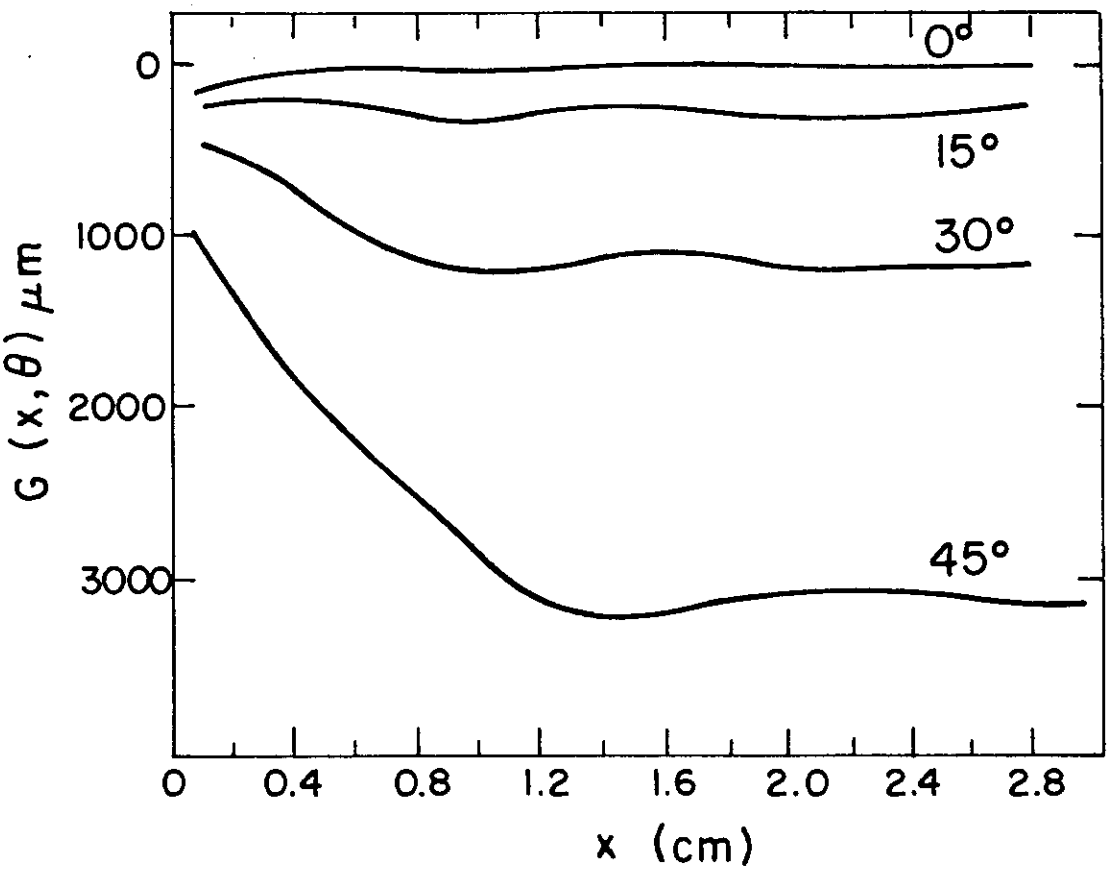


Figure 3: G(x,Θ) vs. track intercept with incident angle as a parameter (D0 field).

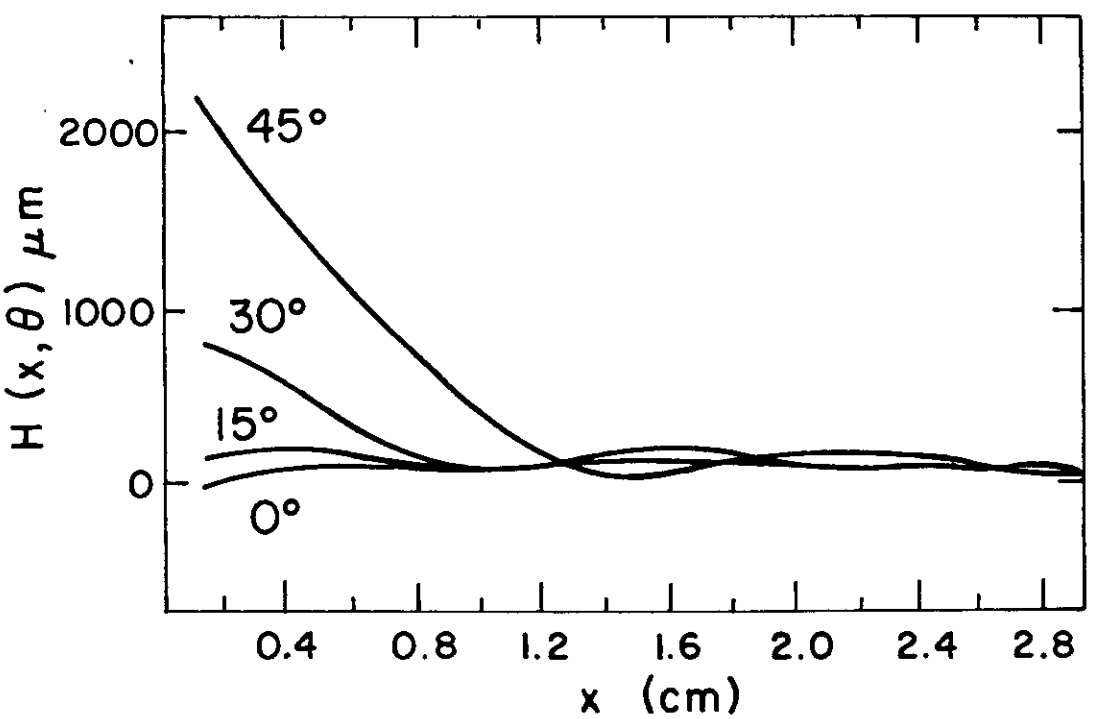


Figure 4: H(x,Θ) vs. track intercept with incident angle as a parameter (D0 field).

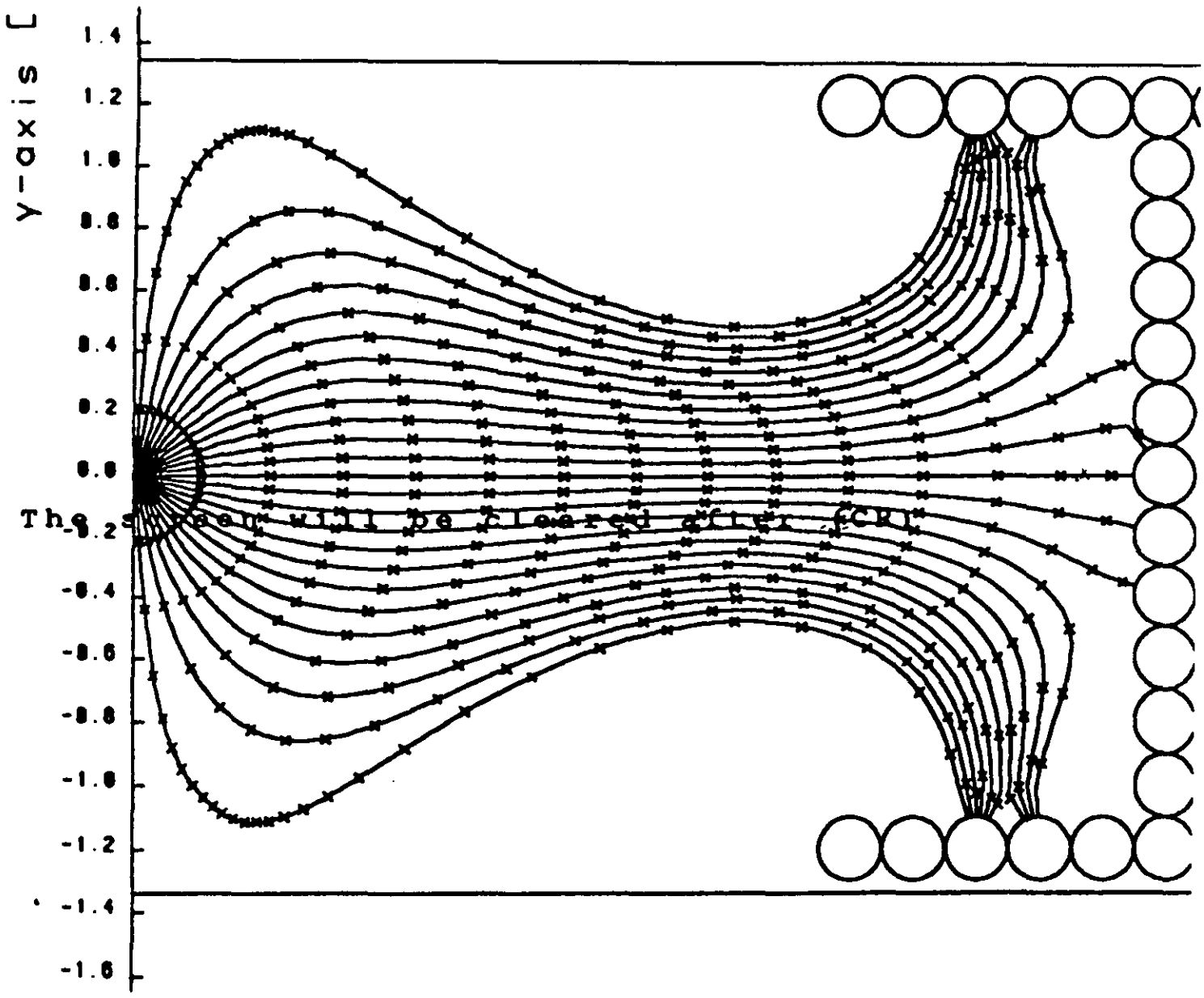


Figure 5: Field lines and isochrones for original CDF drift cells.

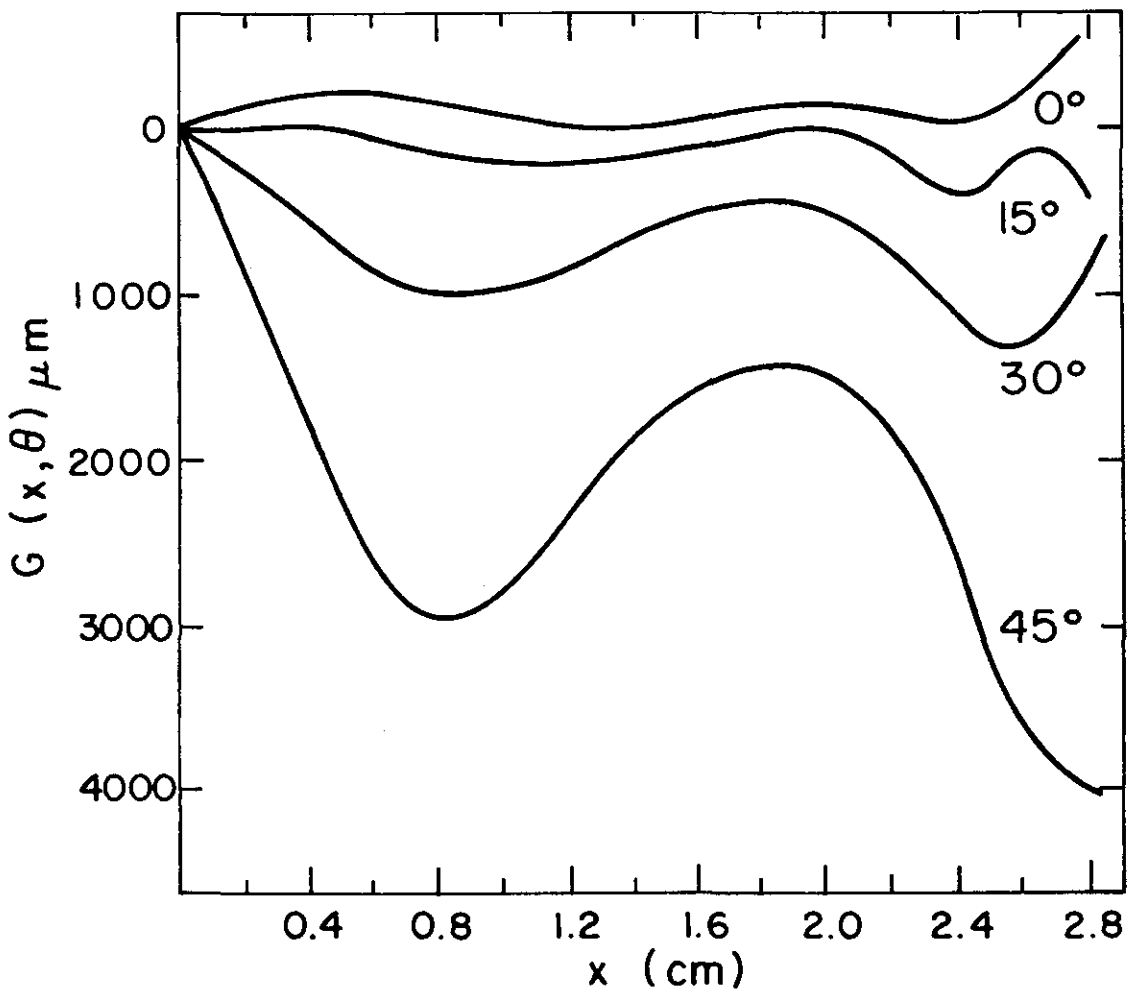


Figure 6: G(x,Θ) vs. track intercept with incident angle as a parameter (CDF field).

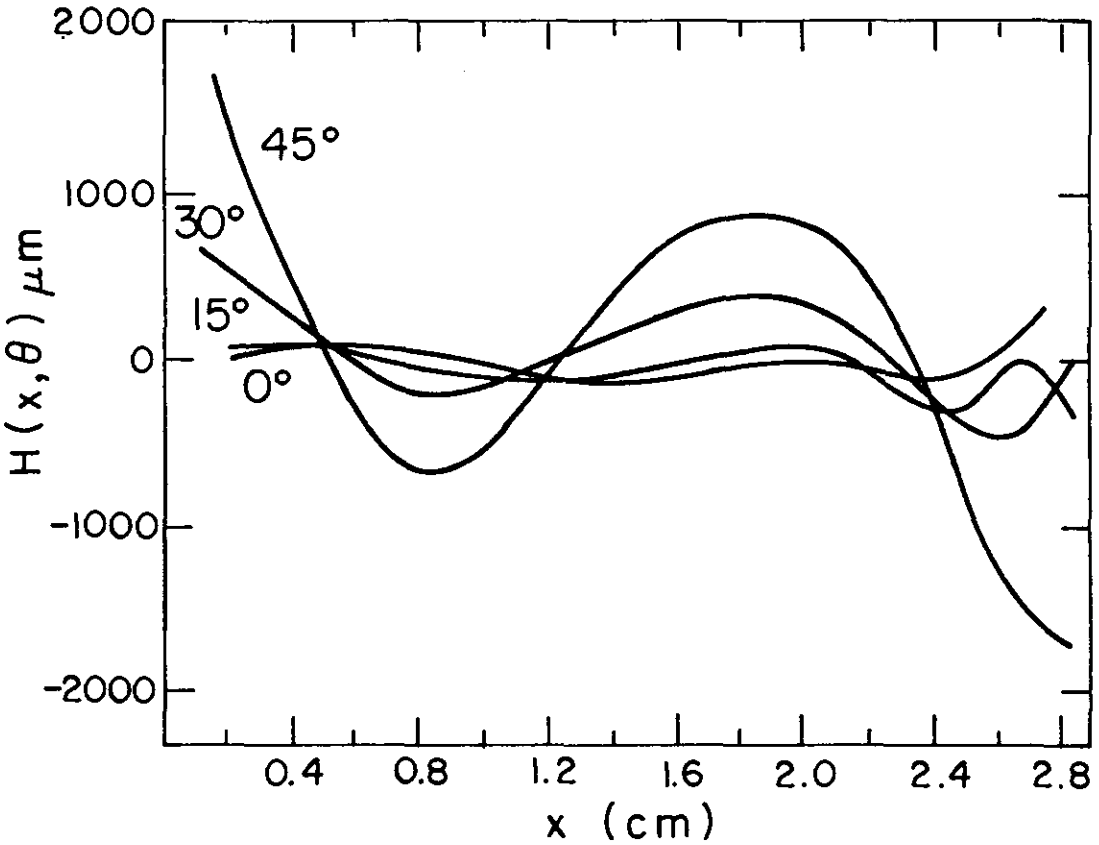


Figure 7: H(x,Θ) vs. track intercept with incident angle as a parameter (CDF field).

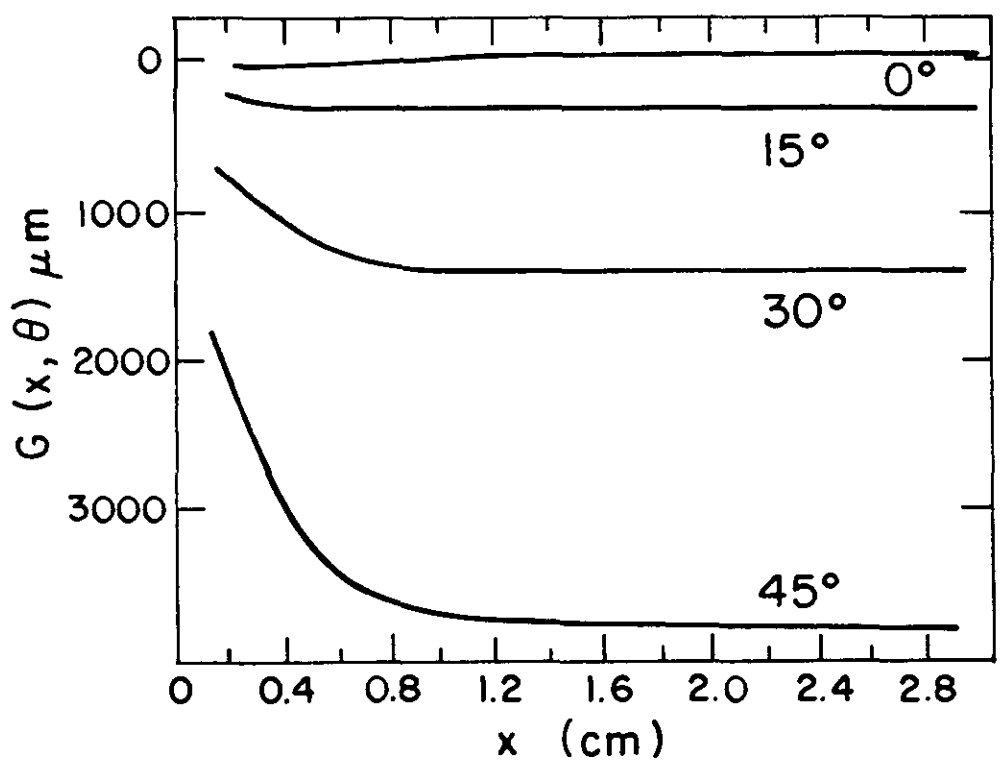


Figure 8: G(x,Θ) vs. track intercept with incident angle as a parameter for multi-sampling drift cell.

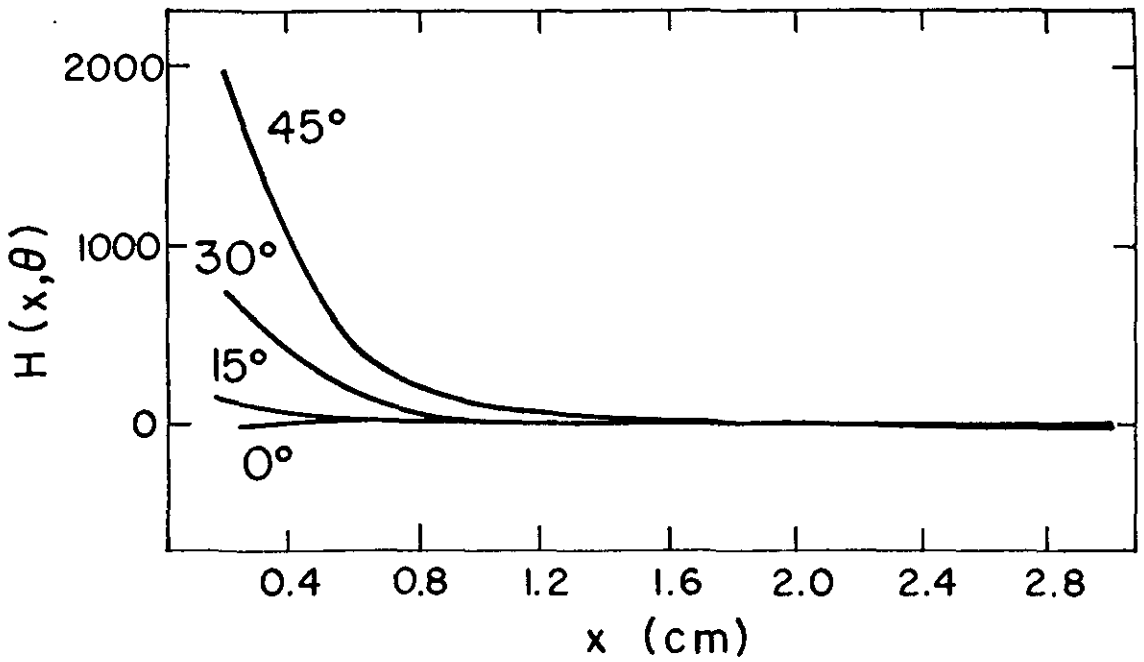


Figure 9: H(x,Θ) vs. track intercept with incident angle as a parameter for multi-sampling drift cell.

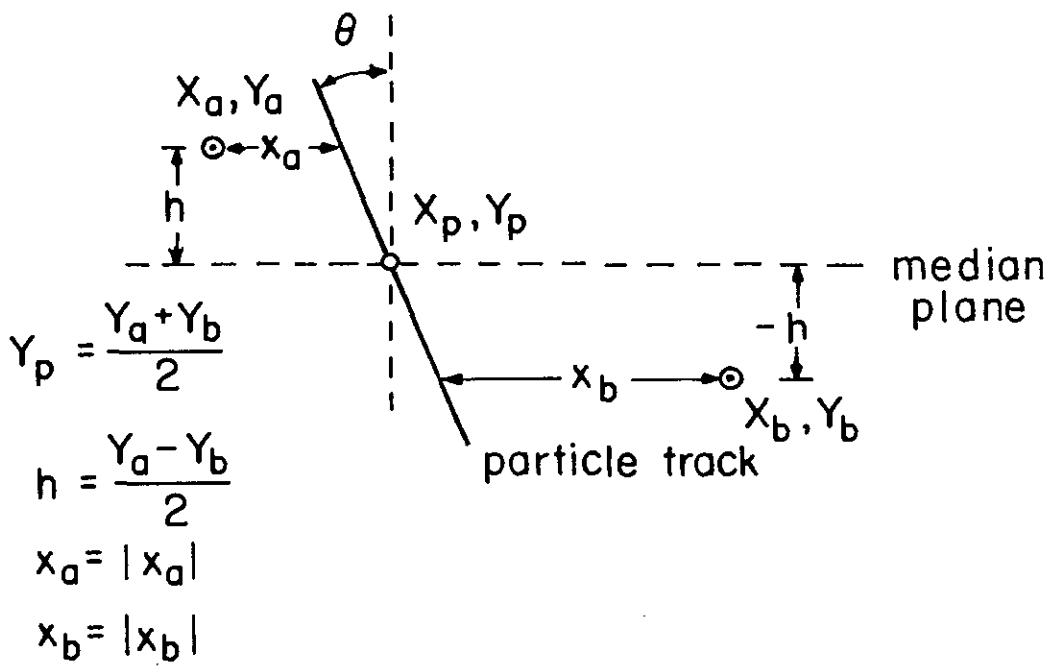


Figure 10: Example of a track traversing two drift-cell planes.

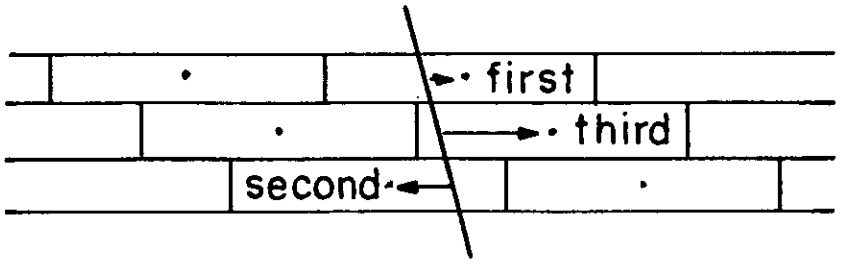


Figure 11: Example of three drift planes with cells off-set by 1/3 cell width.

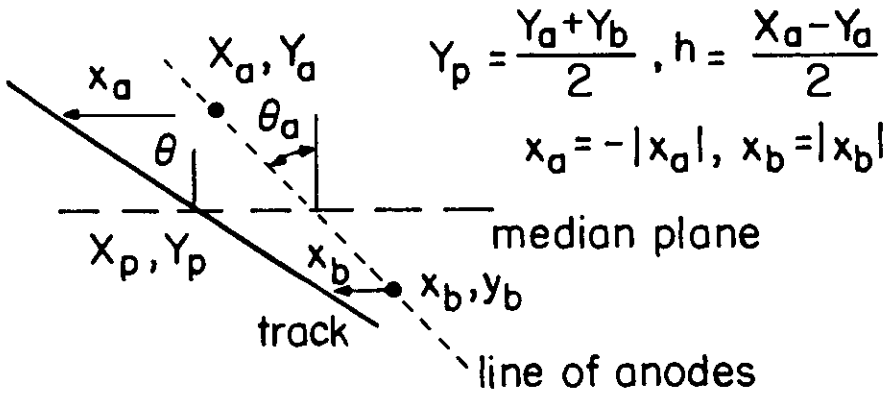


Figure 12: Example of a track traversing two cells and passing both anodes on the same side.