Fermi National Accelerator Laboratory

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DRCELL: A Software Package for Drift Chamber Cell Design

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Designing a drift chamber cell geometry which optimizes resolution and two track separation is not a straightforward task. This paper describes a software package which helps visualize the behavior of drifting electrons within the cell under the influence of electric and magnetic fields. Histograms of chamber pulse shapes and arrival times may be generated. In addition, a calculation of the gas gain is performed. The package presently uses drift velocity, drift angle, gain, and dE/dx parameterizations for 50:50 argon - ethane but modifications may be easily made for other gas mixtures.

The model is straightforward and relies on an analytical form for the electric potential of an infinite series of wires. The electric field is calculated numerically in a small region surrounding any point of interest. In the absence of a magnetic field, the drift direction of an ionization electron is the unit vector along the E field direction. When a perpendicular magnetic field is present, the drift direction is rotated by the Lorentz angle, α.

DETERMINATION OF THE POTENTIAL

The drift chamber potential may be described as the superposition of two proportional chamber cell potentials. We will assume the cathode plane is a flat grounded conducter. This assumption may not be valid if the linear density of cathode wires is low. An approximation to the potential distribution for a series of wires lying in the z direction, carrying charge q per unit length and located at $x = 0, \pm s, \pm 2s, \ldots$, $y=0$ is:[1]

$$V_p(x,y) = -\frac{q}{4\pi\epsilon_o} \ln\left\{4\left[\sin^2\left(\frac{\pi x}{s}\right) + \sinh^2\left(\frac{\pi y}{s}\right)\right]\right\} + \text{Constant}$$

where s is the wire spacing. This is the potential distribution within a proportional wire chamber when the anode/cathode spacing exceeds the wire spacing. The accuracy of this approximation is estimated by DRCELL, using a procedure described in a later section.

In a drift chamber, alternating wires have a different wire diameter and voltage. This necessitates superimposing two proportional chamber potentials of different wire spacing with properly adjusted charge per unit length. Letting $V_p(s) = V_p(x,y)$ describe the proportional chamber potential as a function of the wire spacing, the drift chamber potential may be written:

$$V(x,y) = AV_p(s) + B_pV(2s) + C. \qquad (1)$$

By specifying the potential on the anode wire, the potential on the field shaping wire, and the potential on the cathode plane, the constants may be derived. The electric field is then easily calculated from the potential.

DESCRIPTION OF THE PROGRAM

The main program, DRCELL, requests an input file to determine the cell geometry, wire potentials and the Lorentz angle. In addition, several switches are read in to direct DRCELL to generate graphics or histograms. The inputs are:

GRAPHICS	Switch to enable graphics
META	Switch to write a meta file
HISTS	Switch to generate histograms
NTRACK	# of tracks to generate in TRKPLOT
WS	Wire spacing
GAP	Distance from anode to cathode
ARAD,AHV	Anode wire diameter, and voltage

FSRAD,FSHV	Field shaping wire diameter and voltage
ICODE	Gas mixture code
MAGON	Switch to turn on magnetic field
EFIELD	Switch to plot the E field - EPLOT
ISOCHRONE	Switch to plot an isochrone - ISOPLOT
TRKGEN	Drift electrons from tracks - TRKPLOT

All inputs must be specified in units of millimeters, nanoseconds, degrees or volts. Figure #1 is an example of an input file for a small cell beam drift chamber operating in a 15 kG magnetic field. At present, there is only one gas mixture code, ICODE = 1, to parameterize the drift velocity, Lorentz angle, gain and ionization for 50:50 argon - ethane bubbled through ethyl alcohol at -1^{o} C. The parameterization will be described in a later section along with a procedure for adding additional gas mixture codes.

The constants A, B, and C in equation 1 are next determined in the subroutine POTINIT by solving the equations:

$$\begin{aligned} V(ARAD,0) &= AHV \\ V(WS\text{-}FSRAD,0) &= FSHV \\ V(0,GAP) &= 0. \end{aligned}$$

This requires inversion of a 3 x 3 matrix in the subroutine LINEQ. At this point the potential is completely determined. POTINIT also prints the value of the drift field and velocity in the vicinity of the cathode plane.

After the constants are determined, the accuracy of the approximation is estimated by calculating the potential at various points along the cathode plane, V(x,GAP), where $0 < x < WS$. Obviously, the potential should be zero at every point. DRCELL prints out the largest value of V at the cathode divided by the field shaping wire potential. The accuracy of the potential distribution within the cell is better than this estimate. For a small cell drift chamber with 5 mm wire spacing, 6 mm gap, and realistic wire potentials, the accuracy is better than .8%.

PLOTTING THE ELECTRIC FIELD

The subroutine EPLOT plots twenty E field lines from the cathode plane to the wire plane. The field lines are spaced such that the density of lines is proportional to the local charge density induced on the cathode. To achieve this, a 1000 point integration is made of the E field near the cathode plane, over a distance of one wire spacing. The values of the E field are also stored. "Near" means within a distance of 2.5% GAP. The integral is divided by the number of lines to get the average E•dl/field line, EDL. Starting from the center of the cathode plane, a field line is started whenever the local sum of the stored E field values exceeds EDL.

The electric field line is drawn from the starting value, (x_o,y_o), by finding the electric field direction from the equations:

$$E_x(x,y) = (V(x+STEP/2,y) - V(x-STEP/2,y))/STEP$$
$$E_y(x,y) = (V(x,y+STEP/2) - V(x,y-STEP/2))/STEP$$

where STEP = (.005)GAP. A new value of x is found by adding an amount dx to the starting value, $x \rightarrow x + dx$, where

$$dx = STEP\ [e_x \cos(\theta) + e_y \sin(\theta)]$$

A similar equation gives the amount dy to be added to y:

$$dy = STEP\ [-e_x \sin(\theta) + e_y \cos(\theta)]$$

Here, (e_x,e_y) is the unit vector in the direction of E(x,y), and $\theta = 0$. This process is repeated until the boundary of a wire or the cell boundary is found. Figure #2 is the plot produced by EPLOT using the input file of Figure #1.

PLOTTING ISOCHRONES

The module ISOPLOT plots lines of equal drift time. The user is first requested to input the drift time, DRTIME. The procedure of the previous section is followed, except a "drift line" is followed instead of an electric field line. When no magnetic field is specified, the "drift line" and the electric field line are the same. A drift line is started at the surface of the anode wire and the angle θ is calculated from the local electric field and gas mixture code. Thirty six field lines are drawn at equal angles around the anode wire. For each field line, a local sum of the drift time from the anode wire is accumulated until the requested isochrone time is reached. The drift time is STEP/DRVEL, where DRVEL is the drift velocity defined in a later section. The isochrone gives a visual indication of the optimum cell orientation to achieve the shortest drift chamber signals.

GENERATING DRIFT CHAMBER SIGNALS

The module TRKPLOT generates graphics displays of electrons drifting from the track to the anode and field shaping wires and also generates histograms. The user is first requested to enter the track intercept and slope. A calculation is made of the endpoints of the track segment which could create a signal on the central anode wire. This section of the track is plotted with a wide line style to distinguish it from non-contributing portion which is displayed with a dotted line style. The average number of electrons to generate is calculated from the contributing track length and XIONS, the number of primary ions expected per millimeter. The actual number of electrons which is generated satisfies a Poisson probability distribution. Each ionization electron is randomly located on the contributing track segment and is drifted to a wire. If the HISTS switch is set, histograms are generated of 1) the arrival time of the first electron, 2) the arrival time of the last electron, and 3) the arrival time of every electron. The parameter NTRACKS determines the number of track segments generated. All generated tracks have the same intercept and slope. The histograms, along with knowledge of the electronics chain, permit an estimate of the two track separation.

PARAMETERIZATION OF OTHER GAS MIXTURES

Modification of the source code is required to model other gas mixtures than 50:50 argon - ethane. The source file PARAMS.FOR contains the functions DRVEL, DRANG, TOWN, and XIONS which parameterize the drift velocity, Lorentz angle, Townsend coefficient, and dE/dx.

The drift velocity for ICODE = 1 was parameterized by the equation

$$\mathrm{DRVEL} = .0527\ (1 - e^{-(.00162)E^{1.562}})$$

where E is the electric field. The constants were fit to the data published in ref. 2. A list of the data and a comparison to the fit is shown in Table 1. This parameterization is not valid for high electric fields, since there is a falloff in the drift velocity which is not modelled. For standard chambers, where the drift electric field is less than ~2 kV/cm, this is not a problem. Close to the anode wire, the electric field certainly exceeds 2 kV/cm but the drift path to the anode wire is very short.

The Lorentz angle in a 1.5 T magnetic field was parameterized by a similar equation:

$$\mathrm{DRANG} = 1.10\ e^{-(2.17\times10^{-5})E^{1.961}}$$

where the values of the fit were fit to data from ref. 2. The parameterization was chosen to give the expected qualitative asymptotic behaviour in the limit of very large electric fields. The agreement with the data is not as good in a χ^2 sense, but the differences are probably acceptable for most applications.

Finding a parameterization for the Townsend coefficient, α, is not as easy. A list of possibilities is described in ref. 3. The form chosen for ICODE = 1 is that of Korff:

$$\alpha = A\ e^{-B/\sqrt{\bar{E}}}$$

The values of A and B chosen are preliminary and will be revised in the near future.

References

[1] G. A. Erskine, Nucl. Instrum. and Meth. 105 (1972) 565

[2] M. Atac, Nucl. Instrum. and Meth. A249 (1986) 265

[3] V. Palladino and B. Sadoulet, Nucl. Instrum. and Meth. 128 (1975) 768

Table 1

Comparison of Lorentz Angle and Drift Velocity parameterizations to data

E kV/mm	V_d (data) mm/nsec	V_d (fit) mm/nsec
49.2	0.0269 ± .0007	0.0269
73.8	0.0388 ± .0009	0.0389
98.4	0.0463 ± .0011	0.0463
123.0	0.0503 ± .0012	0.0500
147.6	0.0517 ± .0013	0.0517
172.2	0.0520 ± .0013	0.0524

E kV/mm	Lorentz angle (data) radians	Lorentz angle (fit) radians	Difference degrees
49.2	1.043 ± .0066	1.050	0.7
73.8	1.007 "	0.996	0.6
98.4	0.927 "	0.923	0.2
123.0	0.835 "	0.839	0.2
147.6	0.738 "	0.746	0.5
172.2	0.655 "	0.651	0.2

.T.	Graphics on
.F.	Metafile on
.F.	Histograms on
1,	# of tracks to histogram/plot
6.0,	half gap - mm
5.0,	wire spacing - mm
.020,2300.,	Anode wire diameter and voltage - mm, volts
.150,1000.,	Field wire diameter and voltage - mm, volts
1,	Gas mixture code, must be non-zero
.T.	Magnetic field on
.F.	Plot E field lines
.F.	Plot isochrone
.T.	Plot electrons along a track

FIGURE #1

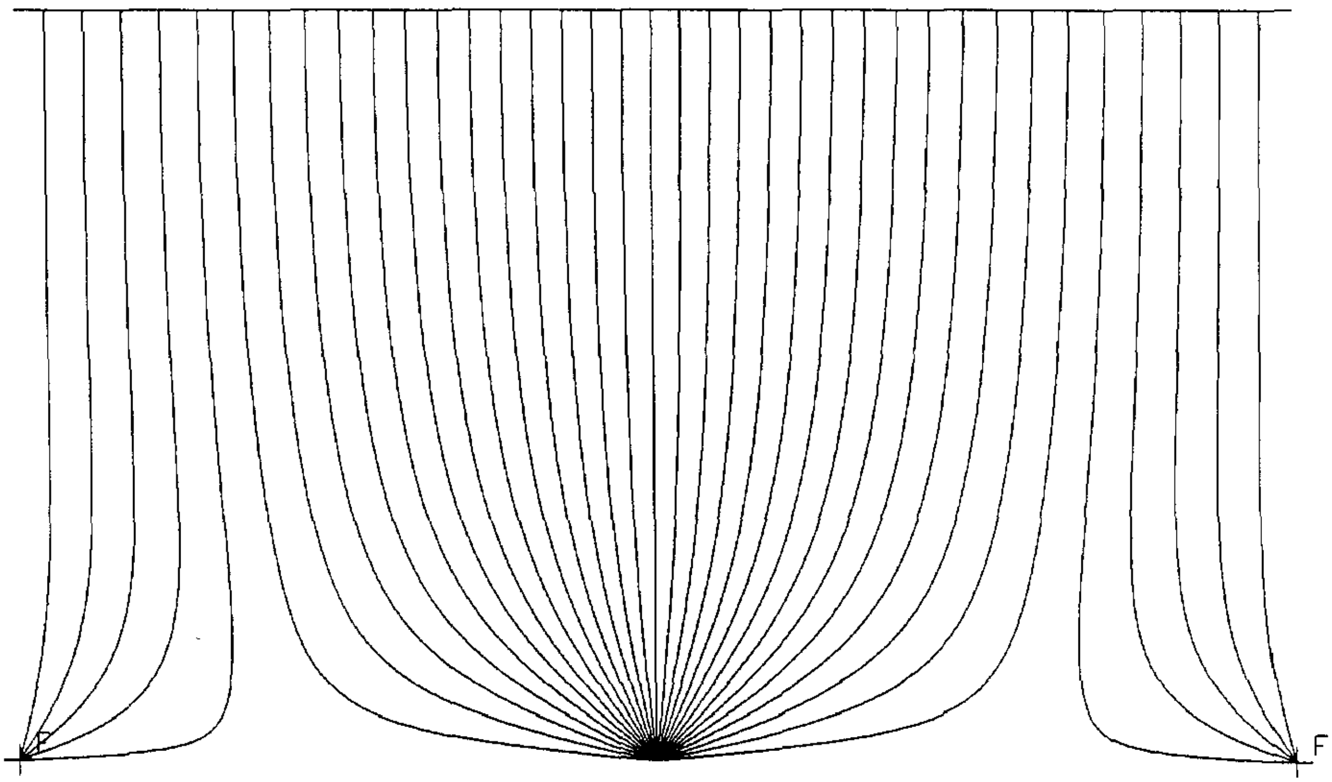

FIGURE #2

Isochrone for 100.0 nsec

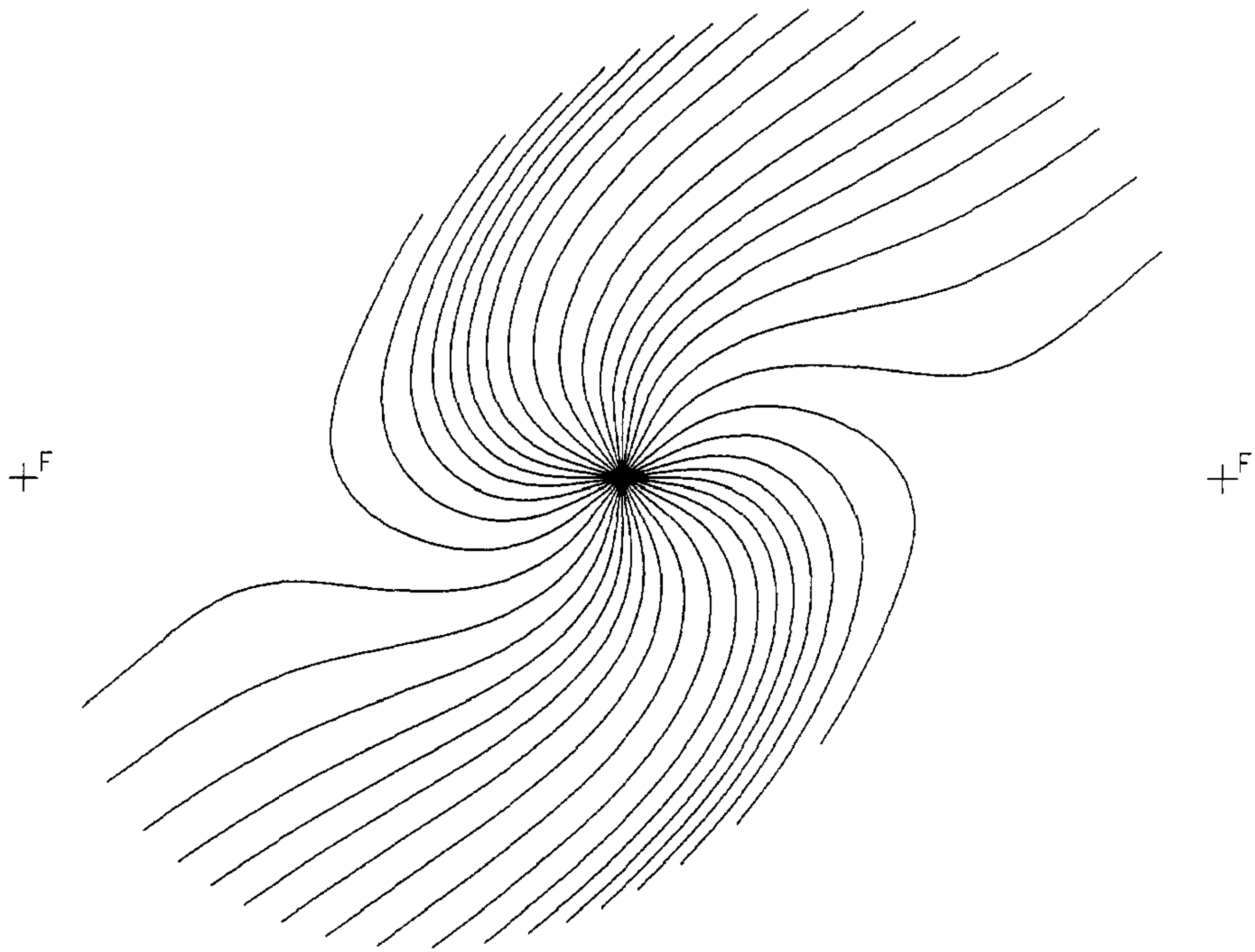

FIGURE #3

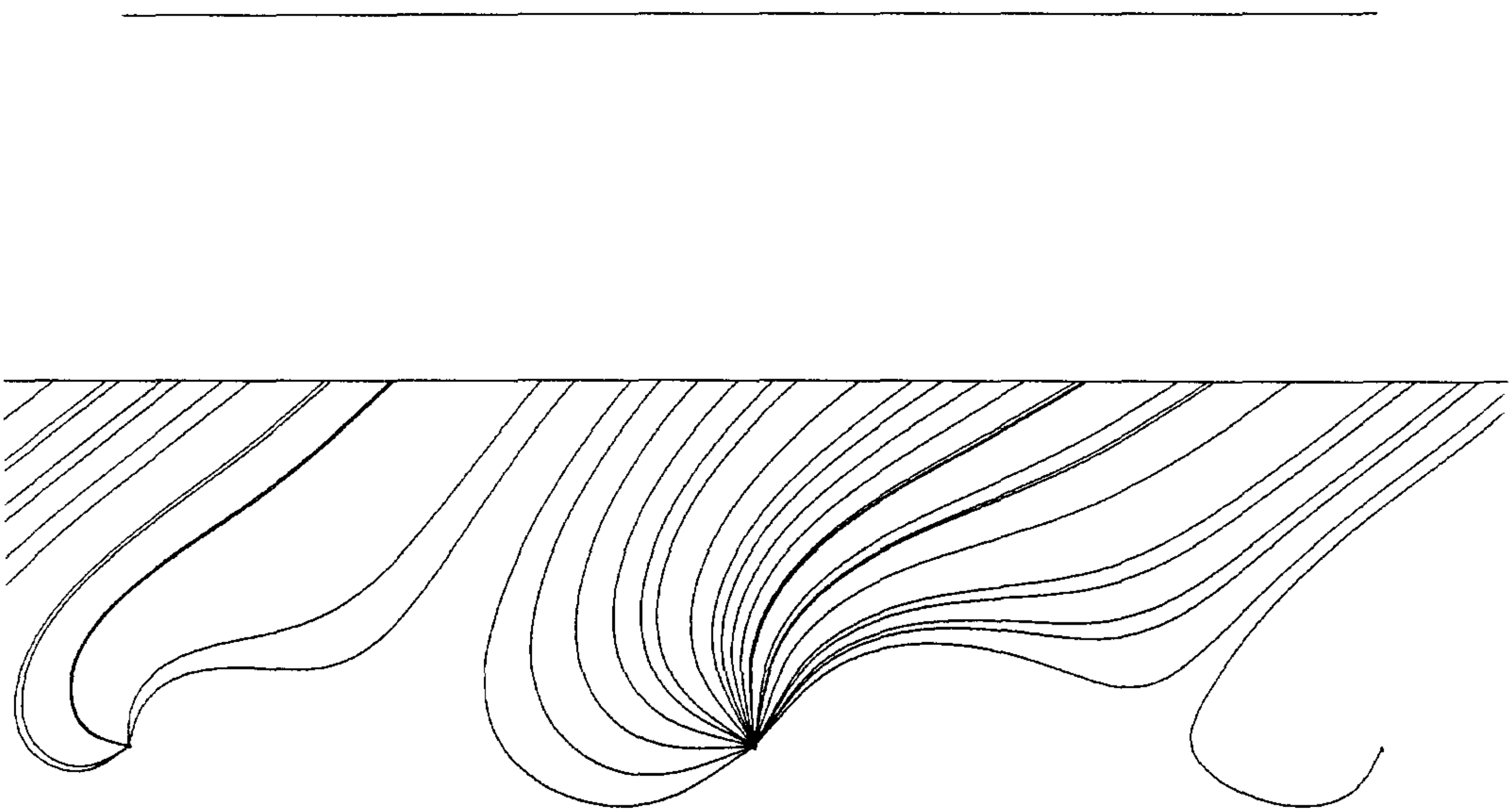

FIGURE #4

Arrival time - ns

```
HBOOK     ID =          1                                   DATE  05/01/89

      62           -
      60           I
      58           I
      56           I
      54           I
      52           I
      50           I
      48           I
      46           I
      44           I
      42           I
      40           I
      38           I
      36           I
      34           I
      32           I
      30           I
      28           I
      26           I  -
      24          -I  I
      22          II -I
      20          II-II  -
      18          I   I- I
      16          I    I I  -
      14          I    I-I  I-      -  -
      12          I      I--II-- - -I  I
      10          I            I-I II- I
       8          I              I-I I I-     -
       6          I                  I II-- --I ---
       4          I                  I I  I-I I-I I -----       -
       2          I                  I-I          I-I   I  -- --I  - ---  - -    -

CHANNELS  10    0        1         2         3         4         5         6         7
            1   1234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS  10       2622211111111111 11  1
            1.     410158392164120181392375635674655233334  11 113  1 111  1 1    2

LOW-EDGE 100                         1111111111111111111111111111111111111111111111111
           10   5666667777788888999990000011111222223333344444555556666677777888889999
            1.  9135791357913579135791357913579135791357913579135791357913579135791357

* ENTRIES =        449      * ALL CHANNELS = 0.4460E+03      * UNDERFLOW = 0.0000E+00      *
* BIN WID = 0.2000E+01      * MEAN VALUE   = 0.9150E+02      * R . M . S = 0.2459E+02      *
```

FIGURE #5

```
Last electron time - ns

HBOOK     ID =        3                                  DATE  05/01/89

      3.1
      3                                               -
      2.9                                             I
      2.8                                             I
      2.7                                             I
      2.6                                             I
      2.5                                             I
      2.4                                             I
      2.3                                             I
      2.2                                             I
      2.1                                             I
      2                                      -        I-         -
      1.9                                    I        II         I
      1.8                                    I        II         I
      1.7                                    I        II         I
      1.6                                    I        II         I
      1.5                                    I        II         I
      1.4                                    I        II         I
      1.3                                    I        II         I
      1.2                                    I        II         I
      1.1                                    I        II         I
      1                                      I     ---II-        I  - -     -    -
       .9                                    I     I    I        I  I I     I    I
       .8                                    I     I    I        I  I I     I    I
       .7                                    I     I    I        I  I I     I    I
       .6                                    I     I    I        I  I I     I    I
       .5                                    I     I    I        I  I I     I    I
       .4                                    I     I    I        I  I I     I    I
       .3                                    I     I    I        I  I I     I    I
       .2                                    I     I    I        I  I I     I    I
       .1                                    I     I    I        I  I I     I    I

CHANNELS 10     0        1         2         3         4         5         6         7
         1      1234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS 1.                                  2     111321        2  1 1     1    1
         0      0000000000000000000000000000000000000000000000000000000000000000000000

LOW-EDGE 100                         1111111111111111111111111111111111111111111111111
        10      5666667777788888999990000011111222223333344444555556666677777888889999
        1.      9135791357913579135791357913579135791357913579135791357913579135791357

* ENTRIES =         20      * ALL CHANNELS = 0.1700E+02      * UNDERFLOW = 0.0000E+00      *
* BIN WID = 0.2000E+01      * MEAN VALUE   = 0.1458E+03      * R . M . S = 0.2049E+02      *
```

FIGURE #6

```
First electron time - ns

HBOOK     ID =         2                                               DATE  05/01/89

      9.25
      9                                          -
      8.75                                       I
      8.5                                        I
      8.25                                       I
      8                                          I
      7.75                                       I
      7.5                                        I
      7.25                                       I
      7                                          I
      6.75                                       I
      6.5                                        I
      6.25                                       I
      6                                          I
      5.75                                       I
      5.5                                        I
      5.25                                       I
      5                                          I-
      4.75                                       II
      4.5                                        II
      4.25                                       II
      4                                          II-
      3.75                                       I I
      3.5                                        I I
      3.25                                       I I
      3                                          I I
      2.75                                       I I
      2.5                                        I I
      2.25                                       I I
      2                                          I I
      1.75                                       I I
      1.5                                        I I
      1.25                                       I I
      1                                          I I   - -
       .75                                       I I   I I
       .5                                        I I   I I
       .25                                       I I   I I

CHANNELS 10      0        1         2         3         4         5
          1      12345678901234567890123456789012345678901234567890

CONTENTS  1.                             954   1 1
          0      00000000000000000000000000000000000000000000000000

LOW-EDGE 10      55555555555566666666666666666666777777777777777777
          1.     34455667788990011223344556677889900112233445566778
          0      94949494949494949494949494949494949494949494949494
          0      77777777777777777777777777777777777777777777777777
          0      11111111111111111111111111111111111111111111111111

* ENTRIES =          20     * ALL CHANNELS = 0.2000E+02     * UNDERFLOW = 0.0000E+00     *
* BIN WID = 0.5000E+00      * MEAN VALUE   = 0.6690E+02     * R . M . S = 0.1028E+01     *
```

FIGURE #7