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Performance of the SLD Central Drift Chamber Prototype*

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1. Abstract

A two-cell prototype of the SLD Central Drift Chamber has been tested using CO_2–isobutane (92% -8%) at one atmosphere. Average single wire resolution of 55 μm was achieved. Charge division tests indicate a resolution for the final design of $\lesssim$ 0.5% of wire length. dE/dx separation of π/e should be useful up to at least 7 GeV/c. 100 MHz waveform digitizers were used in parallel with conventional timing and integration techniques. The results show equivalent performance for single tracks and a two pulse resolution better than 1 mm.

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2. Introduction

The Central Drift Chamber (CDC) is the main charged particle tracking device in the SLD detector.[1] It has a 1 *m* outer radius and a 20 *cm* inner radius and will consist of 10 cylindrical superlayers, 4 axial and 6 at small stereo angles. The wires are 180 *cm* long. Each layer is divided azimuthally into cells approximately 6 *cm* wide. As shown in Fig. 1, each cell has 8 sense wires, which are separated from one another by two guard wires. An outward going track will have 80 measurements. In order to handle the high cell occupancy that may occur, waveform digitizers (WFD) will be used on both ends of the sense wires. WFD's which digitize at 100 *MHz* should provide resolution in drift distance, charge division position and total ionization sufficient to meet the stringent requirements of SLD.

In this paper we present results derived from a two–cell prototype chamber with WFD's used in parallel with conventional first-electron sensitive TDC's and charge integrating ADC's. The conventional electronics is capable of measuring only a single pulse on each wire. Some of our results have been reported earlier.[2]

A gas mixture of 92% CO_2 and 8% isobutane at atmospheric pressure has been tested. Gas gain was $\approx 10^5$. The cell design provides a uniform drift field of $\approx 1\ kV/cm$, and a drift velocity of 9 $\mu m/nsec$. The drift velocity is higher in the high field region around the sense wire thus reducing the effect of different drift paths of the electrons. Similar designs are in a number of recent drift chamber prototypes that use a slow gas.[3]

3. Experimental Setup

The prototype has two full-size non-stereo cells in x and y (Fig. 1), but is only 80 cm long. Extra partial cells were included to obtain a realistic field configuration, but were not instrumented. The prototype was placed in a test beam, and a uniform magnetic field of up to 10 *kG* was applied along the wire direction.

Ten of the sense wires were tungsten (150 Ω each), while the others were stainless steel (1250 Ω each). Low noise, low input impedance (30 Ω) preamplifiers (Laben 5242) were mounted on both ends of each sense wire. Signals from the preamps are amplified in a postamp-discriminator module. The analog output of the postamp is split and fed to both the gated charge integrating ADC (LeCroy 2249W) and the WFD.[4] Drift times were measured using TDC's (LeCroy 2228A) with a 2.5 *nsec* least count. The pulse height threshold used in timing measurements corresponded to 1/3 primary electron. Each wire saw ≈ 16 primary ionization clusters.

The CDC prototype was situated between two sets of four proportional wire chambers (PWC), which provided an external tracking reference along the drift direction as well as along the wire length.

The beam line was equipped with a hydrogen gas Čerenkov counter. Its pressure was set to distinguish electrons from heavier particles. A lead-scintillator shower counter was placed downstream of the CDC prototype to provide additional discrimination between electrons and other particles.

The data reported here were taken with an average of 0.2 beam particles per pulse, and further cuts were applied during the analysis to minimize multi–track events. We report first the results obtained with conventional electronics which are then compared to the results obtained with the WFD.

4. Drift Resolution

Track positions reconstructed from the PWC system were compared with measured drift times to obtain the time-to-distance relationship for each of the 16 sense wires. The measured drift times were then converted to drift distances, and tracks were fitted using the drift chamber hits only. The residual between the fitted track and each of the measurements determines the drift resolution.

Fig. 2 shows the single wire drift resolution as a function of drift distance. An average resolution over the cell of 55 μm was achieved. The resolution expected from a computer simulation[5] of this drift cell and its drift gas is shown by the smooth curve. The agreement is excellent in the region where the simulation was done and shows that the resolution is close to the predicted diffusion limit. The turn-up for large drift distances results from the non-uniform fields close to the field wires.

5. Charge Division Resolution

The hit position along the wire obtained through charge division was compared against the position given by the PWC, and a fit was used to obtain the charge division resolution. In the case of tungsten sense wires, a resolution of 8.4 mm (1.1% of wire length) was obtained. A resolution of 3.1 mm (0.40% of wire length) was achieved in the case of stainless steel sense wires. The PWC tracking resolution of ≈ 0.2 mm contributes negligibly to these results. The resolution is independent of position along the wire. A deviation from linearity was measured that is described by a sine of period equal to the wire length and amplitude of 0.4 % (0.6 %) of wire length for tungsten (stainless steel) wires, respectively. Such a nonlinearity is expected as a consequence of the dispersion of the signal propagating along the wire and the limited band width of the preamplifier.[6]

Charge division resolution is plotted as a function of the total charge in Fig. 3, showing an improved resolution for higher pulse height. The relative performance of tungsten and stainless steel sense wires indicates that the resolution is limited by thermal noise.

For the 180 − *cm* − long CDC thermal noise will be smaller due to the larger wire resistance (factor 0.55), and the reduced effective wire length relative to the true wire length (factor 0.84). The charge integration time can be shortened significantly using WFDs (factor 0.67), resulting in a total charge division resolution of $\lesssim 0.5\%$ of wire length for the planned CDC. The more robust tungsten sense wires will be used, higher resistance stainless steel wire is not needed.

6. dE/dx

The CDC design has been optimized for tracking, while particle identification in the SLD will depend on Čerenkov Ring Imaging Detectors. However, further π/e separation by dE/dx in the CDC is possible, and has been studied. Electrons were identified by requiring a signal from the Čerenkov counter and a large pulse height in the shower counter. Pions were identified by the absence of these signals.

To simulate the final CDC, where 80 hits per track are possible, 5 tracks in the prototype, each having 16 dE/dx samples, were combined into one "track". The average pulse height was computed using a truncated mean method. The 64 samples (out of 80) with the smallest pulse heights were used. Table 1 summarizes the results on π/e separation and shows a comparison with theoretical calculations[7].

Possible saturation effects in gas gain were studied by varying the high voltages. No change in π/e separation was found for gas gains down to 1/5 of nominal.

7. Time and charge using waveforms

A typical readout of the digitized sense wire signal from a single charged particle is shown in Fig. 4a. The waveform analysis measures the drift time by finding the time that the pulse amplitude crosses a constant level threshold. The resolution is then improved by using a two bin linear interpolation with one bin on each side of the threshold crossing. For events selected to have a single charged particle in the chamber, a comparison of WFD times to TDC times indicates that the average timing error is less than 2.7 *ns*, corresponding to an error in the reconstructed drift distance of approximately 25 μm. A more relevant resolution may be obtained by fitting a track to WFD timed hits. Resolutions obtained in this manner for drift times measured with both WFD's and TDC's as a function of drift distance are shown in Fig. 5. The waveform results compare well with the resolution seen using the TDC. Improvements to the WFD modules and the timing algorithm are expected to reduce the average timing error to less than 2 *nsec.*

The average charge division resolution using WFD is presently 11 *mm* for tungsten wires (1.4% of wire length). We believe that the performance will improve with an improved calibration procedure for the pulse height of each of the 10 *nsec* time bucket of the WFD.

8. Two–track resolution using waveforms

Waveform analysis is particularly well suited to resolving multiple tracks. Fig. 4b shows the waveform for a six–track event and Fig. 6 shows the hit pattern of a multitrack event using WFD timing. The tracks are easily identified and have residuals of 60 μm on the average. The efficiency of multiple pulse finding has been estimated using single track data by summing the readouts of two single track events. In these simulated events, the 2 pulse separation is known and can be varied. The efficiency of finding both pulses in the simulated two track event as a function of the two track separation is shown in Fig. 7. The waveform efficiency is better than 90% when the pulses are separated by only 1 mm.

References

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π/e momentum (GeV/c)	π/e separation measured	calculated
4	2.2 σ	3.1 σ
7	1.6 σ	2.0 σ
11	1.2 σ	1.2 σ

Table 1 Average π/e separation compared with theoretical calculations.

Figure captions

Figure 1. The wire pattern for the prototype drift chamber cell. Sense wires are shown as $\times$, guard wires as $+$, and field wires as $\bullet$. Two such cells are instrumented, and partial cells surrounding them help establish the proper electrostatic configuration.

Figure 2. Drift resolution *vs.* drift distance. The average resolution over the 29 mm drift space is 55 μm. The smooth curve is the prediction of a computer simulation of this drift cell and gas.

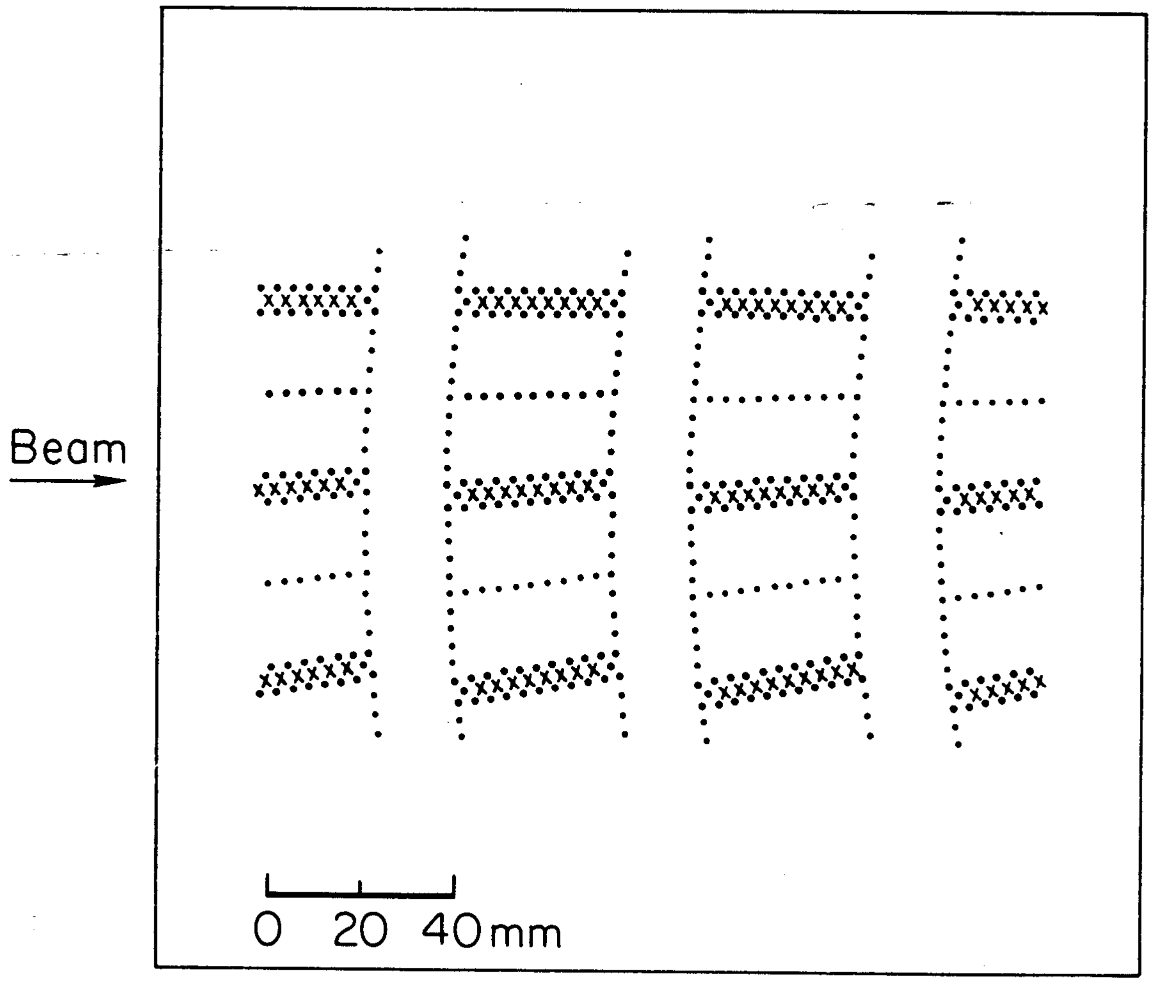
Figure 3. Charge division resolution *vs.* total charge for (a) tungsten and (b) stainless steel sense wires. Resolution limited by thermal noise is linear in 1/charge. The smooth curves show that other contributions to the resolution are small in comparison to thermal noise.

Figure 4. A typical 100 MHz Waveform Digitizer (WFD) readout for a) a single pulse event and b) a multi–track event.

Figure 5. Average drift resolution as a function of drift distance for both TDC and WFD timed hits.

Figure 6. A multitrack hit pattern using WFD timed hits. The sense wires are shown as $\times$, the reconstructed hits and their up/down ambiguity as $\bullet$. The average resolution for the fitted tracks far from the sense wires is 60 μm. The up/down ambiguity is resolved by linking the fitted tracks between the two cells.

Figure 7. Efficiency for finding two pulses as a function of two–pulse separation. A constant 9 $\mu m/ns$ drift velocity has been used to set the horizontal scale.



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5341A1

Fig. 1

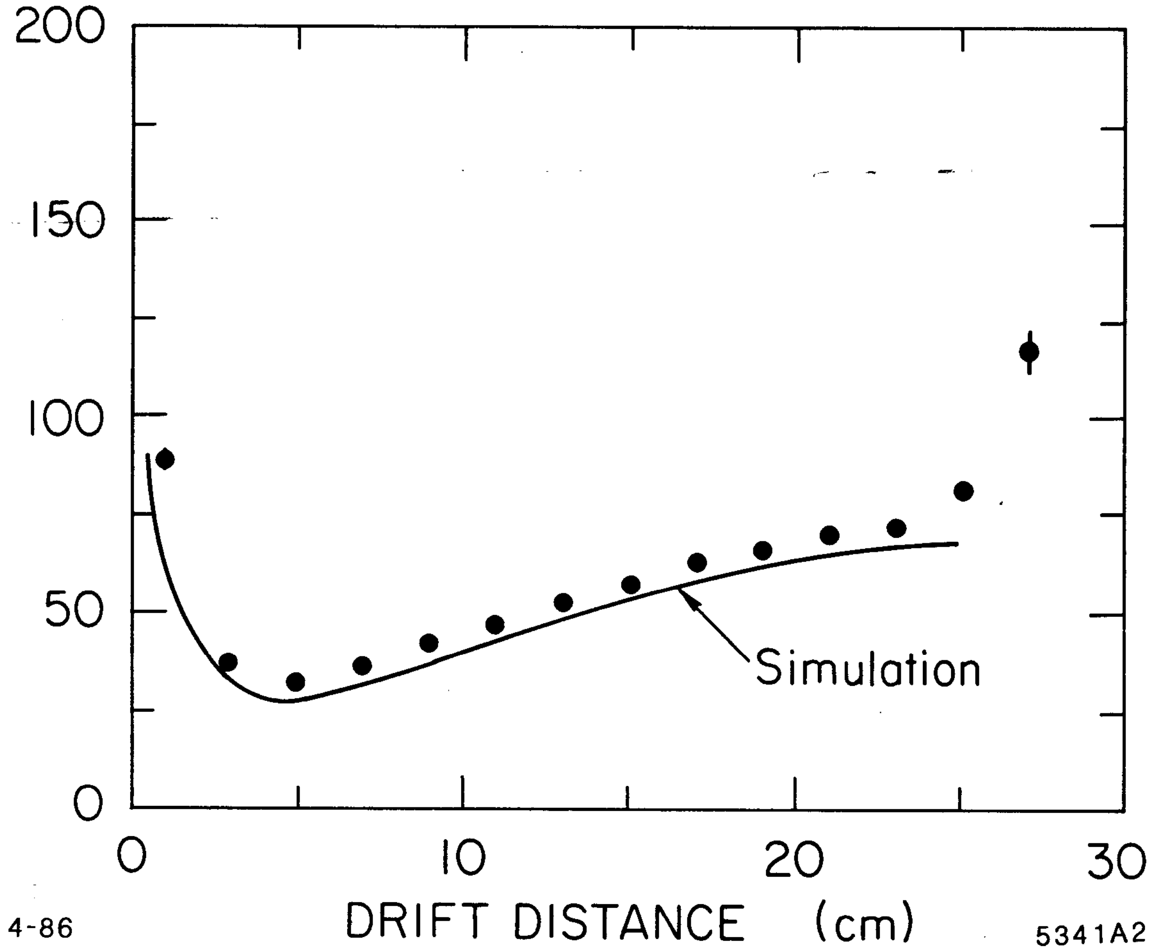
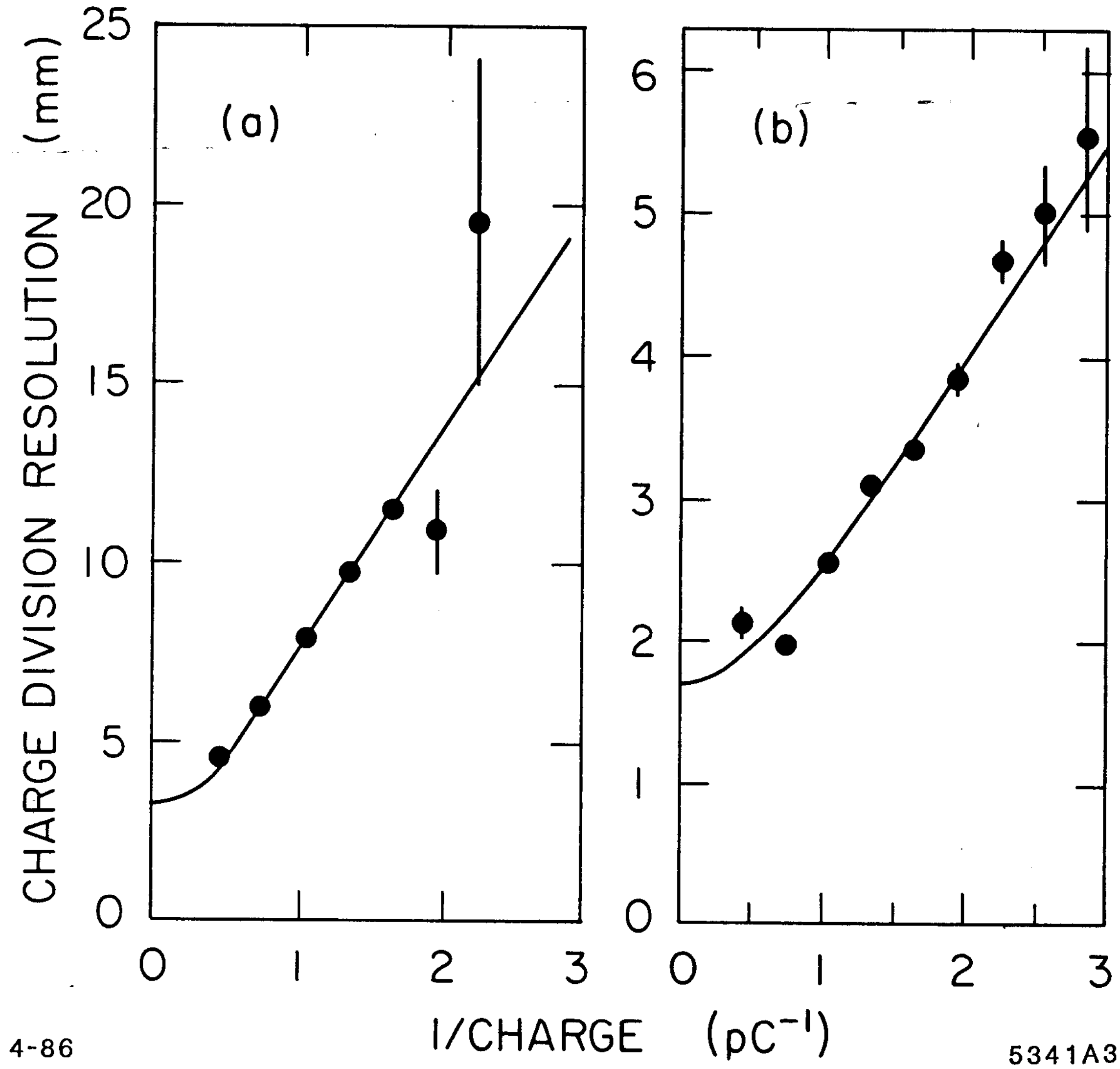

200
150
100
50
0
0
10
20
30
Simulation
DRIFT DISTANCE (cm)
4-86
5341A2

Fig. 2



CHARGE DIVISION RESOLUTION (mm)
(a)
(b)
0
5
10
15
20
25
0
1
2
3
4
5
6
0
1
2
3
I/CHARGE (pC⁻¹)
4-86
5341A3

Fig. 3

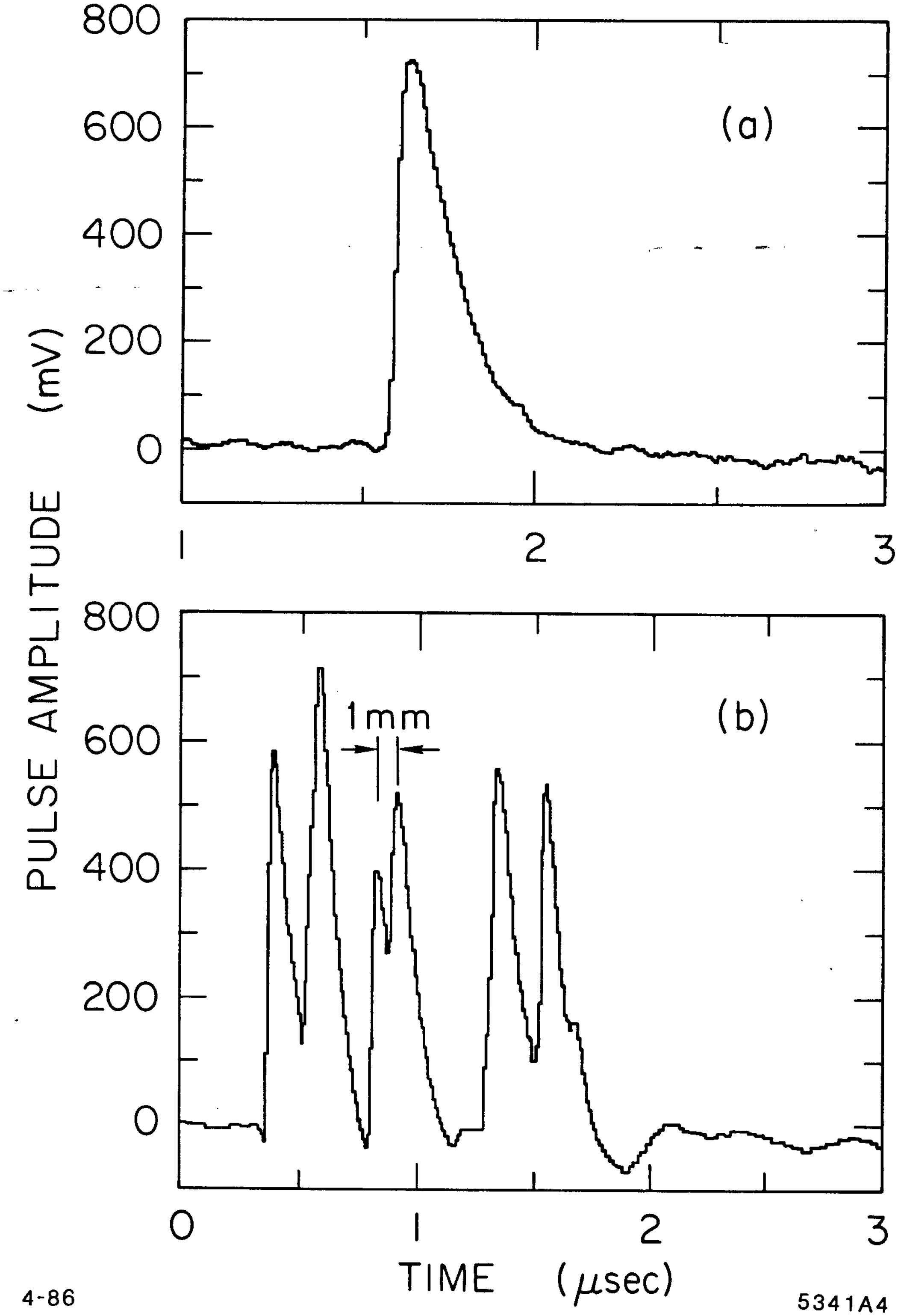

800
600
400
200
0
(a)
1
2
3
800
600
400
200
0
(b)
1mm
PULSE AMPLITUDE (mV)
0
1
2
3
TIME (μsec)
4-86
5341A4

Fig. 4

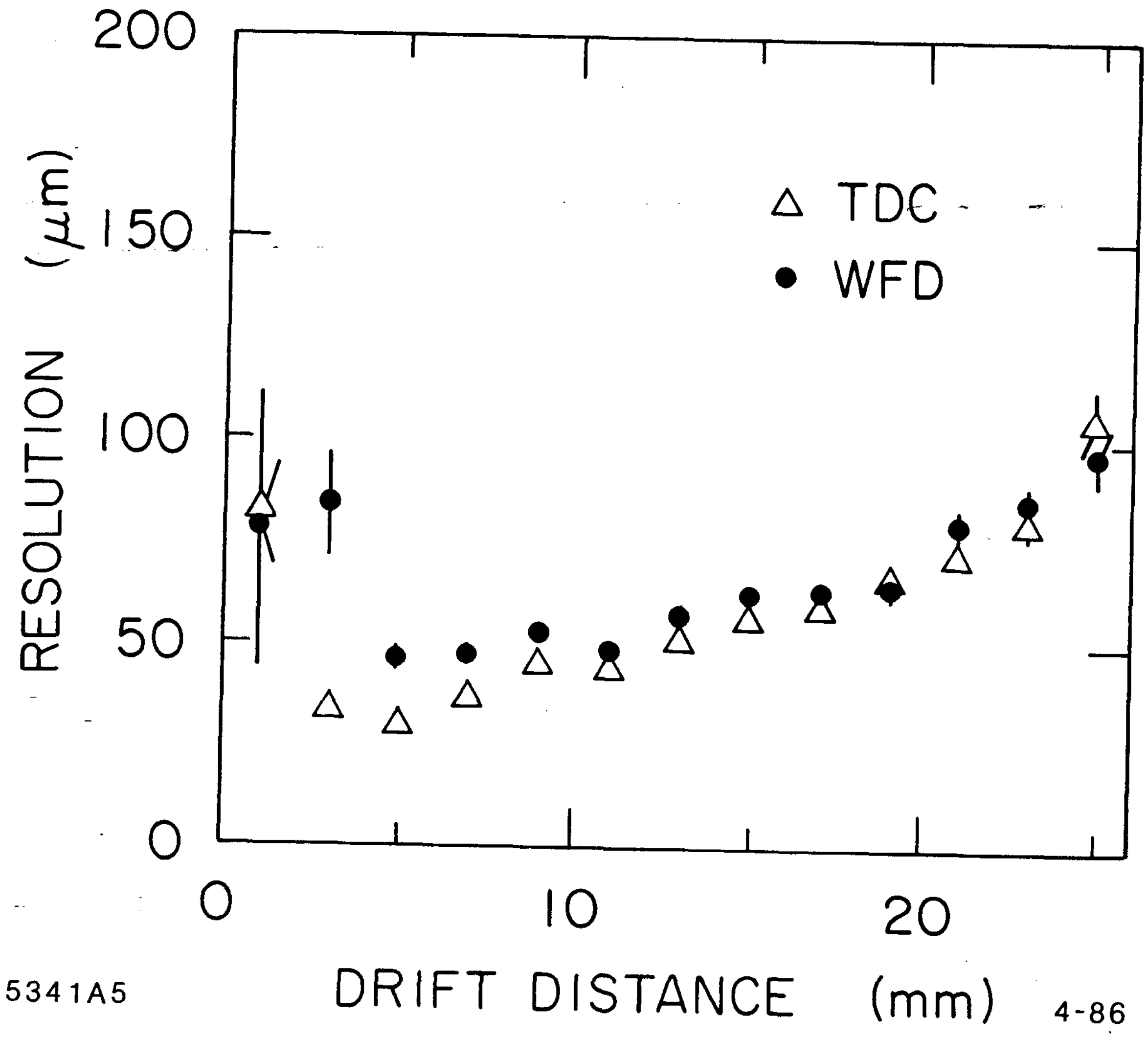

200
150
100
50
0
RESOLUTION (μm)
△ TDC
● WFD
0
10
20
DRIFT DISTANCE (mm)
5341A5
4-86

Fig. 5

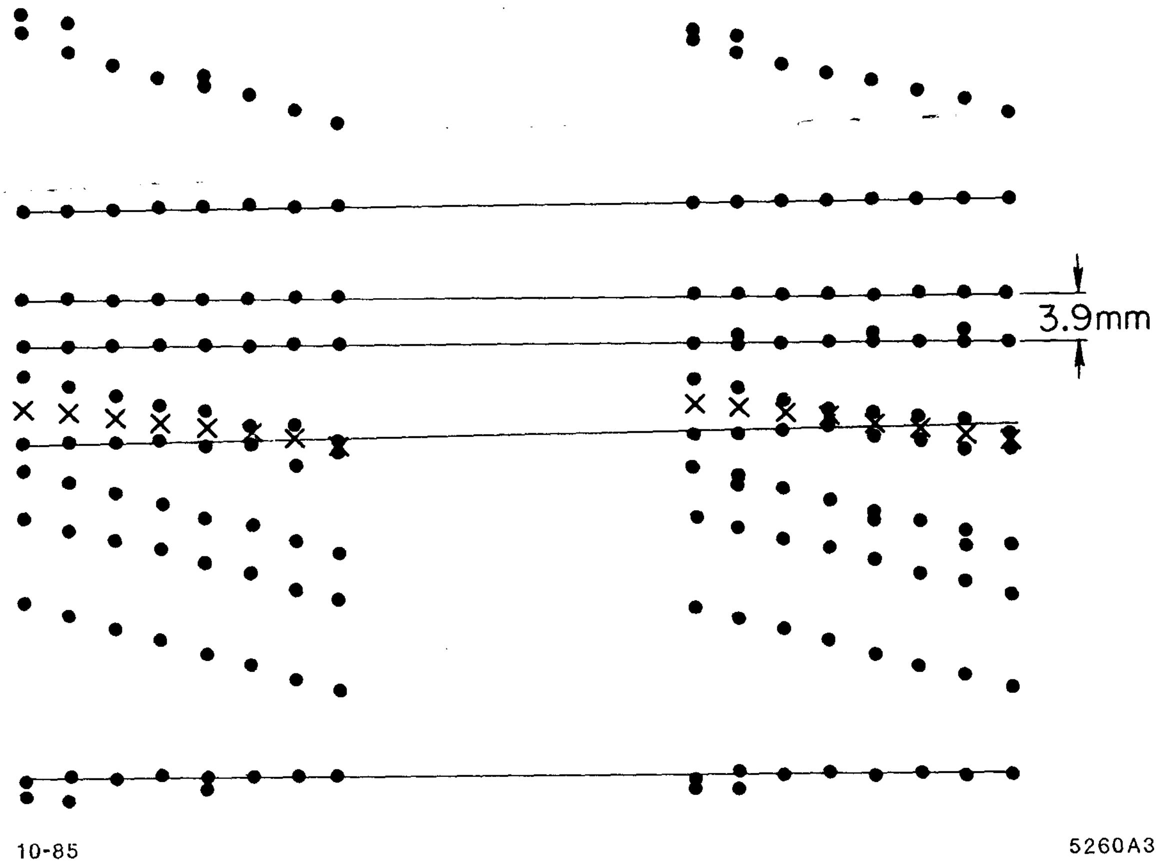


Fig. 6

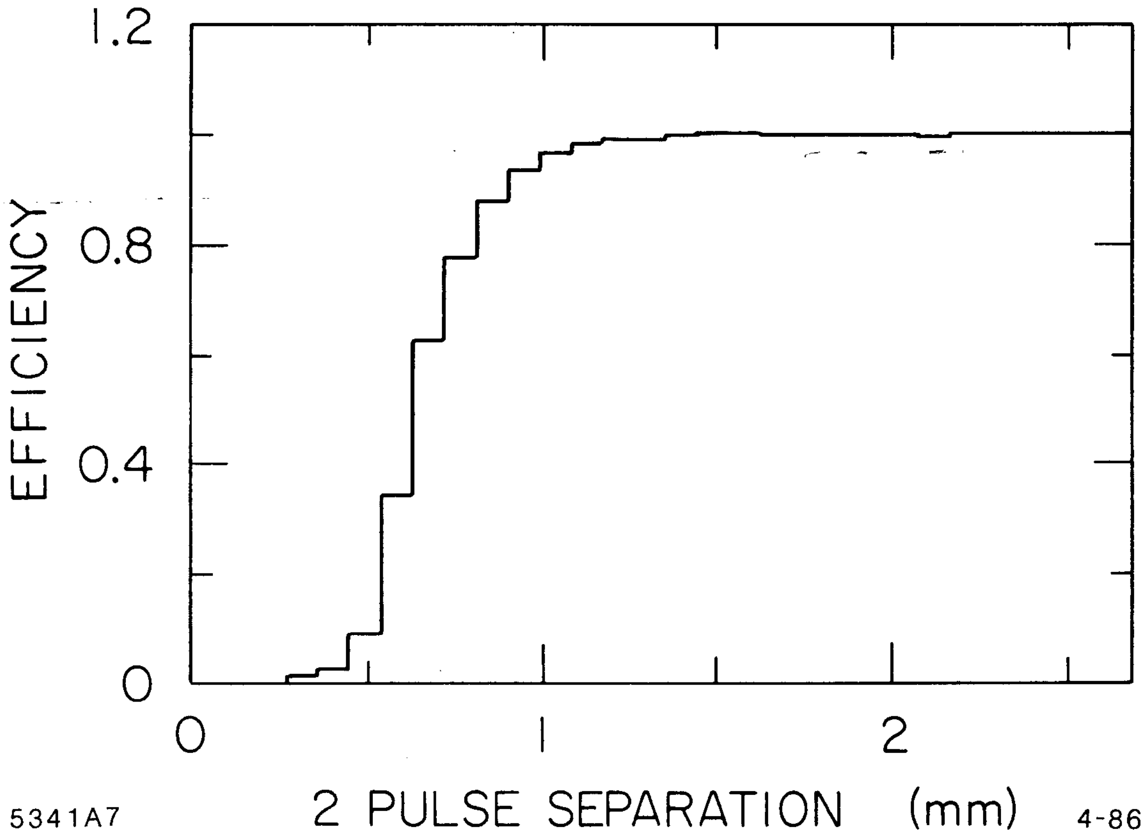


Fig. 7