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R & D Proposal

Development of a Time Projection Chamber with high two track resolution capability for experiments at Heavy Ion Colliders

H. Wieman
Lawrence Berkeley Laboratory, Berkeley, CA, USA

R. Brockmann (*)
GSI, Darmstadt, Germany (***)

R. Renfordt, D. Röhrich, R. Stock, S. Wenig
IKF, University of Frankfurt, Frankfurt/Main, Germany

H. G. Fischer, M. Flammier, J. C. Legrand
CERN, Geneva, Switzerland

V. Eckardt, H. Fessler, W. Rauch, J. Seyerlein
Max-Planck-Institut für Physik, Munich, Germany

I. Tserruya
Weizmann Institut, Rehovot, Israel

A. Etkin, K. Foley, R. Hackenburg, E. Platner (**)
Brookhaven National Laboratory, Upton, N.Y., USA

(*) Spokesman
(**) Projectleader at BNL
(***) Pending internal approval

Contents

Abstract

Experiments at future Heavy–Ion Colliders have to deal with unprecedented high particle fluxes. In the dedicated Heavy–Ion detector at LHC pattern recognition and particle identification are performed by a Time Projection Chamber that operates in a field free region or in a weak magnetic field (0.2 T). A double track resolution of considerably < 10 mm, that is a factor of 2 – 4 better than in existing TPC's, is needed to cope with the high track density. Improvements in the readout modules, analog electronics and longitudinal and transversal single electron diffusion are proposed. The problem of data–acquisiton and –reduction is briefly addressed.

1 Introduction

Time Projection Chambers have proven to be reliable detectors for tracking and identification of high energy charged particles. They are operated at Electron – Positron colliders (PEP,LEP) detecting events with a moderate average charged particle multiplicity per event (10 – 30) as well as in an environment with events that have a comparatively high multiplicity as they occur in fixed target relativistic Heav–Ion experiments at CERN (NA36, NA35), BNL (E–810) and LBL (EOS–TPC). In these reactions the accepted multiplicity is as high as 200 charged particles (CERN NA35) corresponding to a particle density of 0.1 – 0.2 part./cm^2. Even in this environment of high particle density tracking and particle identification can be done.

For the dedicated Heavy–Ion Detector at LHC a TPC is planned for pattern recognition and particle identification.

Given our experience with the NA35–TPC at CERN we feel that the particle density of 0.1 – 0.2 part./cm^2 is about the limit in density at which one can reliably do tracking a n d particle identification. The upper limit in particle density that one can tolerate is given by the double track resolution. This value is in the case of the NA35–TPC about 1.1 cm, corresponding to a particle density of about 0.26 part./cm^2, assuming the average distance between tracks equals the double track resolution.

In Fig. 1(a,b) it is demonstrated how the signal amplitudes of nearby pads do overlap when two tracks pass through the chamber at a spatial distance of 1.0 cm . One realizes that the padresponse function (PRF) of the two tracks are starting to overlap and the accurate determination of the total amount of charge per track which is needed for the particle identification gets difficult. Therefore exact double track resolution is desirable (Fig. 1c,d).

A better double track resolution is needed not only for improving the particle identification but also for the determination of large source sizes by Bose-Einstein interferometry. In Fig. 2 the dependence of the source size R [fm] as function of the two-track resolution and the transverse momentum is shown. To measure large source sizes (> 40 fm) as they might occur for low transverse momentum pairs a double track resolution of < 1 cm is needed. These large source sizes might be created at LHC energies and we want to be prepared to measure these radius parameters with state of the art detector technology.

Furthermore, we can expect that an improved double track resolution will also be needed for an unambiguous recognition of the track pattern. This is important in particular in a detector configuration as discussed for the dedicated Heavy–Ion Detector at the LHC where the momenta of the particles will be measured with a combination of a Silicon-Tracker for precise position determination and a TPC for pattern recognition. In such a configuration the unambiguous matching of tracks from the TPC and the Silicon–Tracker is crucial.

A TPC with a reduced pixel size will produce a considerably higher volume of data compared with a conventional TPC. Therefore we regard already at this stage online data reduction, including clusterfinding and tracking as an integral part of our effort. We also link our ideas on this topic with this proposal as these ideas might in the future influence the on-chamber electronics.

2 Improvements in double track resolution

The double track resolution is about 3 times the width sigma of the signal. This width is determined by the following parameters:

1. distance between the pad- and the sensewire-plane
2. width of the pads
3. single electron diffusion in the gas
4. shaping time of the padsignal
5. drift velocity of the positive ions and electrons in the gas

In addition there are effects related to the orientation of the tracks with respect to the padplane, the so called $\tan\alpha$ effect and the wire ExB effect (Lorentz angle). These effects of widening can be influenced by a proper choice of the relative angle between pads and the "average" track if any. This optimization procedure will not be discussed here.

The width of the pads has to be such that the induced signal on the padplane is sampled by 2 – 3 pads per hit. So the crucial parameter in improving the readout chamber remains the distance between pad and sensewire plane.

The improvements that we envisage will result from a different technique of constructing the readout modules, from the reducing of the shaping time of the electronic signal and the choice of the gas and its pressure. In particular a proper choice of the gas is quite important as is demonstrated by the following numbers: A frequently used gas in TPC's is Ar/CH_4 (91/9) mixture. The sigma of the single electron diffusion of this gas in the longitudinal direction is of the order of 300 $\mu m/(cm)^{1/2}$ and in the transverse direction 530 $\mu m/(cm)^{1/2}$. For a TPC with a maximum driftlength of $L = 2.5$ m (LHC–TPC) this would give for the average driftlength of $\langle L \rangle = 1.25$ m a width for the single electron diffusion of $\sigma = 4.4$ mm in the longitudinal direction and $\sigma = 7.3$ mm in the transverse direction.

The width of the PRF in "Aleph type" readout modules is of the same order of magnitude (3.3 mm).

To improve the double track resolution it is therefore essential to reduce the single electron diffusion and develop readout modules accordingly.

The single electron diffusion can be reduced by choosing a cooler gas or by going up with the pressure in the TPC. Increasing the pressure changes the single electron diffusion as $1/\sqrt{p}$ while the accuracy in determining a space point improves as $1/p$.

In the Aleph–TPC one has taken advantage of the fact that the single electron diffusion in the transverse direction is reduced by about a factor of 7 by the "omega-tau effect". For the LHC–TPC this effect does not apply as the TPC is operated in a very low magnetic field or in a field free region.

Regarding the gas it is intended to explore a cooler gas and make tests also with a pressurized TPC.

The R&D project is subdivided into four major projects which work in a coordinated way together:

1. Readout chambers
2. Analog Electronics
3. Single electron diffusion studies
4. Data acquisition and reduction

In the following the details of these four projects are discussed.

3 Improvement of readout chambers

The two track resolution perpendicular to the drift direction is mainly determined by the wire-to-pad geometry of the readout chamber and the electron diffusion in the operating gas. For simplicity we neglect smaller contributions like the $\tan\alpha$ effect. Then one can express the width of the final signal $\sigma = \sqrt{\sigma_0^2 + \sigma_{\mathrm{diff}}^2(x)}$, where σ_0 is the width of the padresponse function (PRF)which is approximately the distance between sense wire and padplane and σ_{diff} the width of the electron distribution after a drift distance x. From our NA35–TPC we know that tracks which are separated by $< 3\sigma$ can be resolved. In Table 1 we show some results for measured PRF's which have been obtained for 2, 3 and 4 mm gaps and 2 different pad widths [1]. The results confirm the above statement. In Fig. 3 the longitudinal and transversal diffusion coefficients in $[\mu m/cm^{1/2}]$ are shown for Ar/CH_4(90/10) the standard TPC gas and $Ar/He/CH_4$ (40/50/10) mixture. It can be seen that for the latter one the transverse diffusion is much smaller.

Padwidth	3 mm			5.5 mm	
Sense/Pad	2 mm	3 mm	4 mm	3 mm	4 mm
$\sigma_{0,\,\mathrm{trans}}$ [mm]	2.20 ± 0.25	2.67 ± 0.25	3.00 ± 0.2	2.83 ± 0.2	3.42 ± 0.25
$\sigma_{0,\,\mathrm{long}}/v$ [ns]	84.2 ± 3	85.2 ± 3	85.3 ± 3	86.0 ± 3	86.8 ± 4

Table 1: σ_{PRF} of several readout geometries

The goal of this proposal is to improve the two track resolution by a factor 2–3; e.g. in respect to the NA35 result (11 mm), a final resolution of 4 ± 1 mm is envisaged. This requires to reduce the σ_{PRF} down to approx. 1 mm on the one hand and the σ_{diff} to the same order of magnitude on the other hand. From the above mentioned diffusion measurement one gets for 1 m average drift length in the last case a $\sigma_{\mathrm{diff}} = 3.6$ mm, which is definetly not small enough. To obtain the necessary further reduction it is unavoidable to operate the TPC inside a magnetic field, or use a cooler gas and operate it in addition under higher pressure. The diffusion reduction, specially under high pressure, is part of the R&D proposal at BNL.

In the following we propose two developments to reach the small σ_{PRF}:

1. Optimization of the conventional sensewire-to-pad geometry with 1 mm plane distance, including padwidth and wire distances, and

2. Development of a readout chamber which uses the technology developed for Micro-Strip-Gas-Chambers (MSGC's).

3.1 Optimization of conventional readout chambers

Up to the NA35–TPC all large chambers (PEP-4, Aleph, Delphi) were built with a 4 mm gap. NA35 used 3 mm and for the NA49–TPC we proposed for the central region with the highest particle density a 2 mm gap. Since the proposal several tests were successfully made (see also Table 1) and no disadvantage for the operation was found. By using the analog signal for particle identification the critical part is the parallelism of the planes. A variation of $3 \cdot 10^{-3}$ in distance creates 1% variation in gain at the wire, which is considered to be acceptable. We believe that also a 1 mm gap can be handled, possibly with a somewhat reduced wire length (50 – 60 cm instead of 80 cm). We propose a more systematic study of wire geometries including electrostatic effects. These tests include also the use of resistive wires and grids.

For the production of the pad plane we are investigating to use the etching technique instead of milling the pad structure. First prototype plates showed high precision for the overall position accuracy and the variation of the pad size. In a next step the reproducibility will be tested. For the future we propose to use industrial multilayer technology which would give gas tightness a priori and would allow easy accomodation of the electronics (preamp. IC etc.) on the backside.

3.2 Development of a readout chamber based on MSGC-technology

During the last few years large progress was made in developing the MSGC's [2]. A typical cross section of such an arrangement is shown in Fig. 4a. Lithographic techniques to produce the anode strips of $< 10\ \mu m$ width are available. Various groups at Pisa, CERN, and Amsterdam have searched successfully for materials in which the bulk and surface conductivity can be controlled. Spatial resolutions of a few 10 μm were obtained and lifetimes of a few years at LHC are expected.

The advantages of this technology for TPC readout are manyfold:

1. The backplane can be easily subdivided into pads for a two dimensional readout
2. The intrinsic resolution power is not limiting the two-track resolution in a TPC.
3. The precision of the gap between the anode strips and the pads can be easily controlled.
4. Due to the induction signal on the outside there is no gas leakage problem. (A large TPC for the LHC Heavy–Ion detector with approx. 10^5 channels would need the same number of feedthroughs with todays construction principles.)

The signal reduction due to the substrate can be partly recovered by using a larger distance between the anode and cathode strips on the surface. In addition there is a difference in the TPC application: The particle track is more or less parallel to the surface and therefore a pad sees the sum of signals from several anode strips, depending on the cathode pad length. A possible electrode arrangement for the TPC application is shown in Fig. 4b.

We propose a 2–step procedure for this development :

1. Construction of a small (approx. 10 x 10 cm^2) readout plate which can be tested in an existing test setup at the MPI Munich to get "the proof of principle".

2. If this is sucessful, work on the developmernt of larger areas can be started. This could also be of general interest for the application of MSGC's at LHC expriments.

4 Electronics

In the high track density environment of LHC, the readout electronics will have to cope with extreme conditions as compared to the "classical" TPC electronics design. In particular, this will concern

- exclusive readout of cathode pads due to excessive occupation density of sense wires; consequently, the readout has to be simultaneously optimized for space resolution and dE/dx capability
- extremely small pad sizes which have to be compatible with novel chamber concepts (see above)
- excellent multiple track resolution by optimization of pulse width in correlation with drift velocity and longitudinal diffusion
- high pad occupation density (of order 10%)
- high electronics packing density.

These constraints call for the development of a dedicated, highly integrated electronics chain. This chain should fulfill a number of principal requirements such as

- good noise behaviour combined with at least 10 bit dynamical range
- very precise pulse shaping (tail suppression on the level of 0.1% or better)
- flexibility in pulse width to allow for a range of detector gases and/or readout chamber designs
- excellent base line stability and insensitivity to load fluctuations
- minimum power consumption
- high radiation resistivity.

4.1 Translinear preamplifier/shaper circuit in bipolar technology

In order to meet the electronics requirements listed above, we propose to develop a novel input stage using current-mirror arrays (translinear amplifier) in bipolar technology. This technique allows to realize and control the basic circuit in convenient steps, from a discrete layout using SMD components via a semicustom version with commercial transistor arrays eventually to a fully integrated ASIC chip.

The principal design of the amplifier/shaper stage is shown in Fig. 5. This design offers several interesting features:

- extremely low input impedance, only limited by the frequency range of the transistor array used
- possibility of low bias currents, therefore low power consumption
- very good protection against LV power decoupling problems, therefore excellent base line stability even under high load fluctuations
- high flexibility in pulse width and shaping using a minimum number of passive elements. This is particularly important for high level integration.
- optimum dynamical range due to absence of bias
- easily available multiple outputs and summing capability (e.g. for trigger purposes).
- good radiation hardness to be expected.

4.2 The shaping problem

If extensive off-line data correction or digital filtering procedures during data transfer are to be avoided, the high channel occupancy combined with the Landau fluctuations calls for very precise tail suppression in the analog input stage. In order to be compatible with the required dE/dx resolution, a suppression to 0.1% or better, referred to maximum pulse height, is indeed required.

The pulse shape of pad signals in a TPC geometry is rather complex. It depends on the details of the chamber and pad geometry. An example is shown in Fig. 6,7 for a "standard" TPC configuration, in comparison to the cathode signal from a closed proportional tube. The $1/t$ tail behaviour of the latter is replaced by a bipolar signal due to the particular motion of positive ions relative to the pad in TPC geometry. The negative undershoot reaches several permille of the peak pulse height and falls right into the normal drift time regime of a TPC.

The elimination of this low-frequency tail calls for time constants which are not readily realizeable in VLSI techniques. Moreover, the necessary undershoot suppression cannot be handled with normal pole- filtering circuitry.

We propose to use the good high-frequency response of the translinear circuit to cut off the low-frequency domain by a simple combination of differentiation and integration with small time constants. The required pulse width can then be achieved by subsequent integration or by the use of transistor arrays with moderate frequency response.

4.3 Simulation results

We have performed extensive simulations of the analog response of the proposed circuit using the proportional chamber signal as input pulse form. For the required accuracy of less than 0.1% referred to peak pulse height, we have met with some problems in arithmetic accuracy and stability with the SPICE [3] simulation package. The SABER program [4] on the other hand allows to follow the pulse shape with good precision to the 10^{-4} level.

In Fig. 8 we present the simulated output signal for the circuit shown in Fig. 5, using the VTC transistor array [5]. Note that the pulse width is not optimum for TPC application. Further widening to the requested 150 to 180 ns is however not expected to present a problem.

4.4 Test version with discrete components

We have realized a test unit of the proposed circuit with SMD components on a simple pc board. As far as the low-quality components available for this test can be characterized for simulation, the measured performance corresponds to prediction. The mere fact that such an approach performs at all speaks for the insensitivity and ruggedness of the proposed design.

In particular, we have measured an input impedance of less than 10 Ω and a dynamical range of 14 bits. The power consumption is on the level of few mW. We are going to study noise performance and detailed pulse shape in the near future.

4.5 Semi-custom realization

In a next step, we propose to proceed to the study of a semi-custom version. Several commercially available transistor arrays can be envisaged and have to be simulated according to their specifications. As packaging and mounting constitute one of the main problems in high-density electronics integration, we want to exploit state-of-the-art technologies [6] for this part of the project.

4.6 Analog storage and digitization

For the time being, we will concentrate on the analog front-end amplifier and shaper stage. A combination with Switched Capacitor Arrays and multi- channel ADC, as they are currently developed at LBL [7] can be envisaged for analog signal storage and digitization.

5 Gas studies at BNL

For the STAR TPC at RHIC an effort is underway at BNL and LBL to optimize the diffusion in the longitudinal drift direction. This problem will be approached by the STAR group from the following directions :

1. A careful measurement of the $1/t$ tail as a function of gas mixtures, drift field values and anode geometries.

2. A study of various gas mixtures as a function of electric drift field conditions to minimize the longitudinal diffusion.

A special chamber will be built that should allow an extensive evaluation of the effects of gas mixture, pressure etc. on diffusion under optimum electric field conditions.The chamber will have at least 50 cm drift and allow electric fields of > 1.2 KV/cm.

This program will be carried out independently and financed by the DOE in the US. However, the TPC groups at LHC and RHIC will stay in close contact to exchange results and ideas in regular meetings and both sides see it as a joint effort to improve the TPC performance for future use at Heavy–Ion colliders.

6 Laboratory and beam tests

The tests with different gases and readout modules will be performed with existing field cages at MPI Munich and in a test chamber at BNL. The tests will be done with existing laser systems first and in a later phase with particle beams at CERN and BNL. It is too early to ask for testbeam time already now. Due to the close relation of this proposal to the NA35/NA49 experiment we would like to perform these tests with our existing apparatus in the H2 beamline at CERN.

Once a configuration has been adopted it could be further studied by its implementation e.g. in the existing NA35 TPC (except tests with higher pressure). The infrastructure of the NA35/NA49 experiment can be made available and at the very end of these studies one could envisage a thoroughly understood readout configuration for the LHC–TPC.

7 Data–Acquisition and –Reduction

In the context of this R&D proposal we feel it is essential to start already now with the planning of the R&D work on data-acquisition and -reduction for the LHC–TPC as hardware and software will be closely related. Our ideas are still vague at the moment, but they will firm up over the upcoming months after we have gained more insight in the analysis of the data from the NA35–TPC. This whole effort is in part parallel to our studies for the NA49 experiment

A TPC with a high two track resolution capabilty will improve the pattern recognition as well as the charge determination necessary for particle identification. But these improvements have to be complemented by a sophisticated cluster finding algorithm. In order to preserve nearby clusters or even overlapping ones, cluster finding cannot be done on a small neighborhood but at least on a local, maybe global scale. That means that even for the first step of data reduction ('zero-suppression') an online tracking scheme may be necessary. Since this zero suppressing is complicated and therefore demands a lot of computing power, a data acquisition system that allows a high speed interconnect between raw TPC data and farms of processors should be envisaged. The approved CERN proposal RD-24: Applications of the Scalable Coherent Interface to Data Acquisition at LHC [8] seems to meet our specifiations. A prototype of a DAQ system consisting of VME-to-SCI bridges (Fig. 9), assuming that the TPC raw data sit in a VME board like in the NA49 design, and some SCI high performance multiprocessors are necessary to evaluate the feasibility of such a system.

The minimum requirement that is needed for a test setup consists of:

- 2 SCI-VME bridges
- 2 SCI processors
- workstations with VME interface

8 Timescale and budget

We estimated that the project will extend over a period of about 2 years, the budget is estimated for this period ,the total costs are 450 KSFR.

The responsibility for the readout chambers is at the MPI, Munich, the electronics development is in the responsibility of the CERN group of this proposal, the gas tests are mainly done at BNL/LBL and some at MPI, the responsibilty for data acquisition and reduction is at IKF, Frankfurt.

The optimization of the conventional readout chambers will be done in the first, the development of the MSGC's will start in the second year.

The efforts on the study of cooler gases etc. at BNL will be about equally spread out over a two years period.

The milestones for the electronics development are in the first year: realization of the in die technology, packaging and study of new mounting technologies. In the second year we will attempt the realization in semicustom macrochip technology (2 turnarounds).

The activities in data acquisition and -reduction will start in the first year. In the second year, depending on the progress of RD-24, we evaluate to implement the SCI bridges and processors.

The BNL/LBL part of the development will be financed by the DOE and is part of the R&D work for the STAR TPC at RHIC. However, we intend a close collaboration between BNL/LBL on one side and CERN/GSI/IKF/MPI on the other side to improve the capabilities of TPC's for future experiments at Heavy–Ion Colliders.

8.1 Budget estimates (in KSFR)

	1992/93	1993/94
Prototype readout chambers (conventional)	20.–	
Prototype MSGC		30.–
Electronics for prototypes	25.–	
Gases	15.–	15.–
Gastests (incl. at high pressure)	60.–	60.–
Resistive wires	10.–	10.–
Electronics development:		
- Realization in die technology	20.–	
- Packing	5.–	
- Study of new mounting technologies	20.–	
- Realization in semicustom Macrochip techn.		50.–
DAQ and data-reduction:		
- workstation with VME interface	50.–	
- 2 SCI-VME bridges		10.–
- 2 SCI processors		50.–
	225.–	225.–

8.2 Cost Sharing

In the following table we summarize the contributions we asked for in the participating institutions. In most cases the approval is pending.

	1992/93	1993/94
BNL/LBL	80.–	40.–
CERN	45.–	60.–
IKF	40.–	50.–
GSI	40.–	55.–
MPI	20.–	20.–
Weizmann Institute	pending	pending
	225.–	225.–

9 Sharing of responsibilities

Design, construction and testing of prototype readout chambers	MPI, Weizmann Inst.
Gastests, incl. high pressure	BNL/LBL, MPI
Electronics development	CERN, GSI
DAQ	IKF, MPI

References

[1] T. Alber, Diploma thesis, MPI Munich, 1992

[2] A. Oed, NIM A263 (1988) 351
F. Angelini et al., Nucl. Phys. B, 23A (1991) 254
N. Geijsberths,NIM A313 (1992) 377
R. Bouclier et al. CERN-PPE/91-108

[3] PSPICE, Microsim Corp., Fairbanks, Calif., USA

[4] SABER, Analog Corp., Beaverton, Oregon/USA

[5] VTC Incorporated, U.C.I., Microelectronique, Les Ulis/France

[6] Flip-chip Technology e.g. SOREP, Centre de microelectronique, Chateaubourg, France.

[7] NA49 Experiment, CERN, SPSLC 91-31, May 1991

[8] A. Bogaerts et al., Applications of the Scalable Coherent Interface to Data Acquisition at LHC, CERN/DRDC 91-45, CERN/DRDC 92-6

Figure captions:

Fig. 1a

Signal amplitude in the transverse (y) and longitudinal drift (z) direction for two tracks separated by a distance $d = 1.0$ cm as measured in the NA35–TPC

Fig. 1b

Contourlines of Fig. 1a for four different padrows

Fig. 1c,d

Same as Fig. 1a,b but $d = 2.5$ cm

Fig. 2

Dependence of the source size parameter R on the transverse momentum, p_T, and the double track resolution

Fig. 3

Longitudinal and transversal single electron diffusion in different gases

Fig. 4

(a) Cross-section of a Micro-Strip-Gas-Chamber, (b) possible electrode structure for a TPC readout module

Fig. 5

Layout of proposed translinear circuit including shaper stage

Fig. 6

Normalized signal amplitude from closed cathode and from pad as function of time

Fig. 7

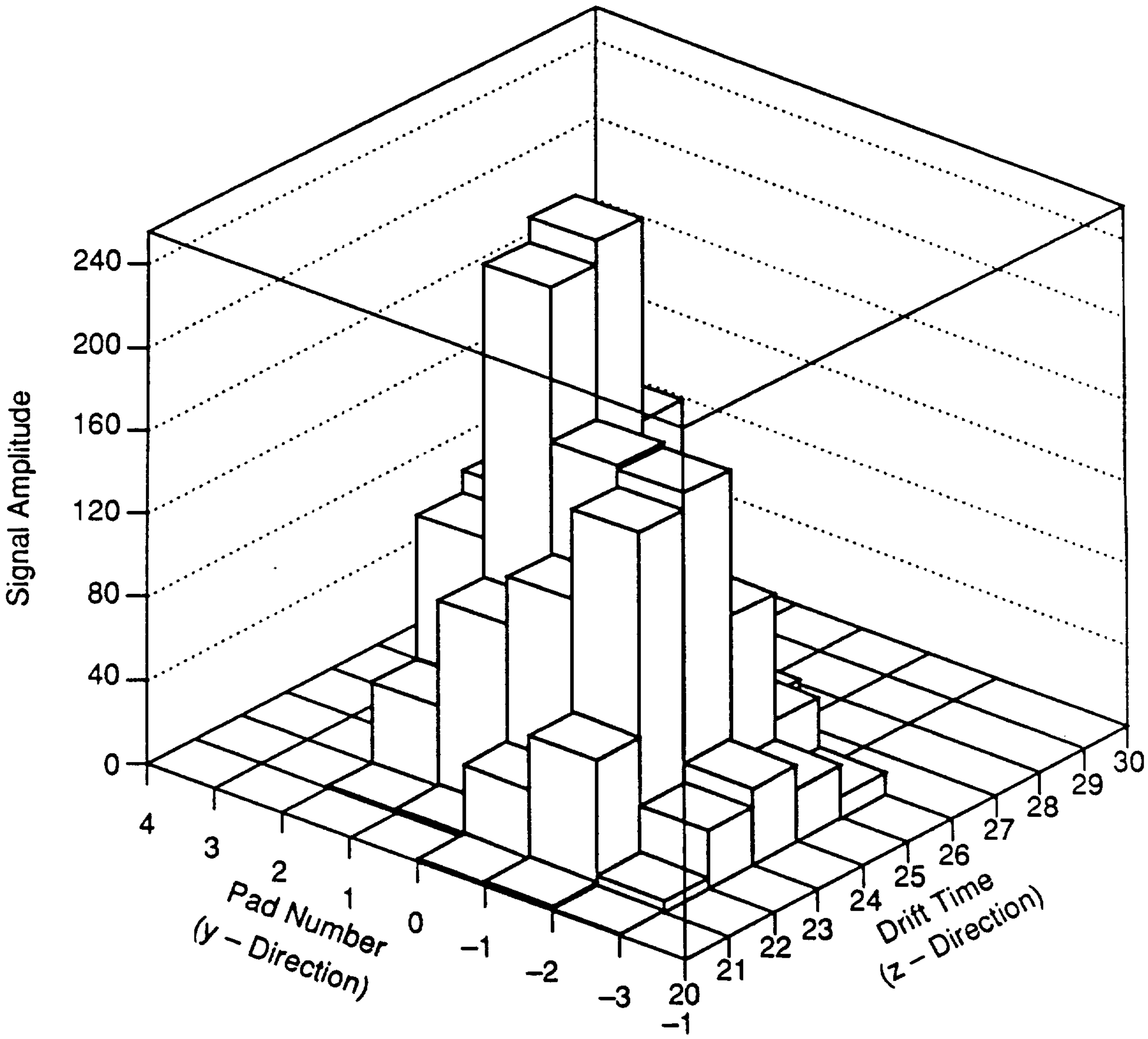
Pad signal as function of time, in permille of peak amplitude

Fig. 8

Simulated output signal of translinear circuit, using cathode current as input

Fig. 9

TPC readout based on SCI



Signal Amplitude
240
200
160
120
80
40
0
4
3
2
1
0
−1
−2
−3
−1
Pad Number
(y – Direction)
20
21
22
23
24
25
26
27
28
29
30
Drift Time
(z – Direction)

Fig. 1a

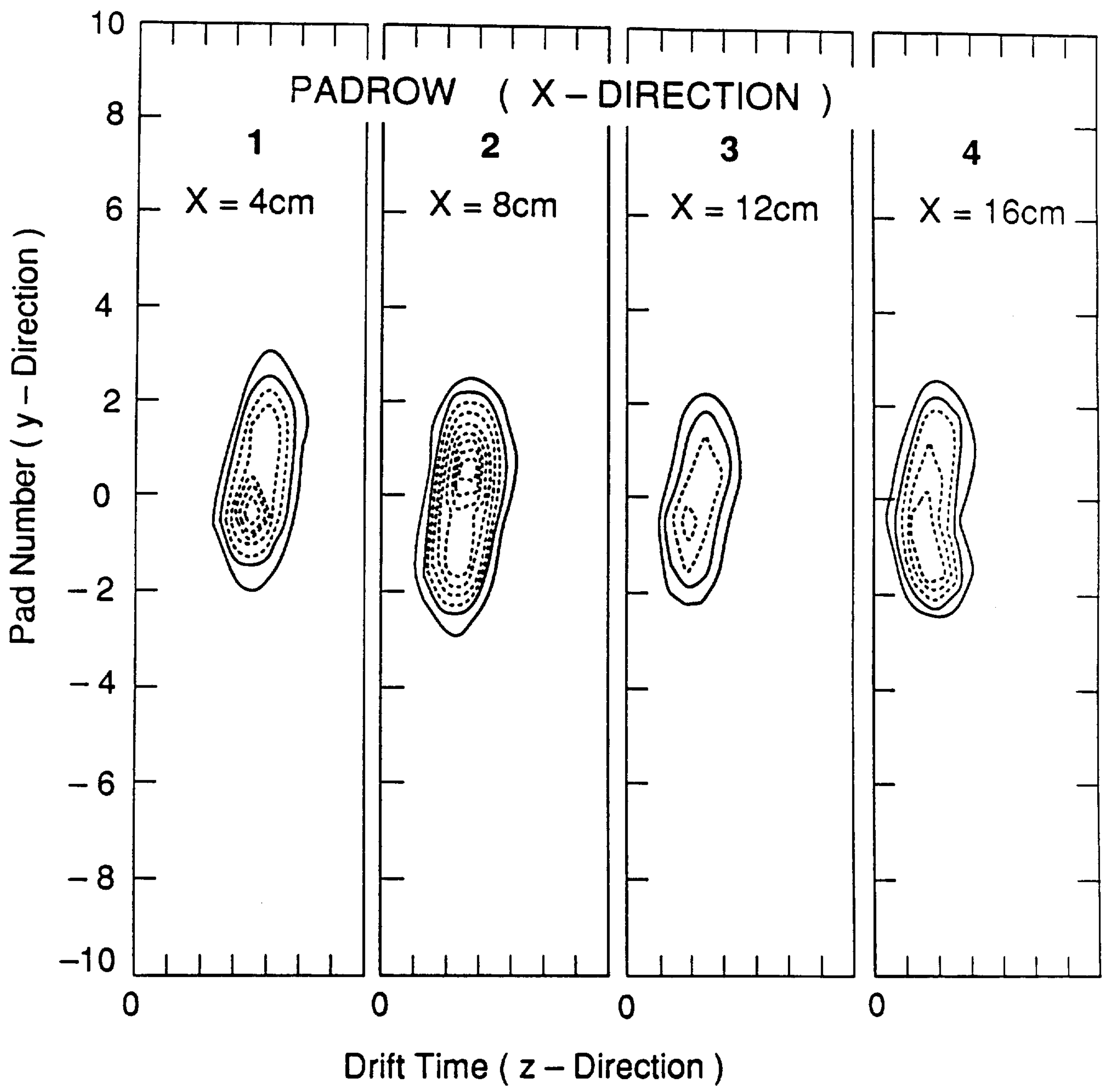

PADROW (X – DIRECTION)
1
X = 4cm
2
X = 8cm
3
X = 12cm
4
X = 16cm
Pad Number (y – Direction)
10
8
6
4
2
0
– 2
– 4
– 6
– 8
–10
0
0
0
0
Drift Time (z – Direction)

Fig. 1b

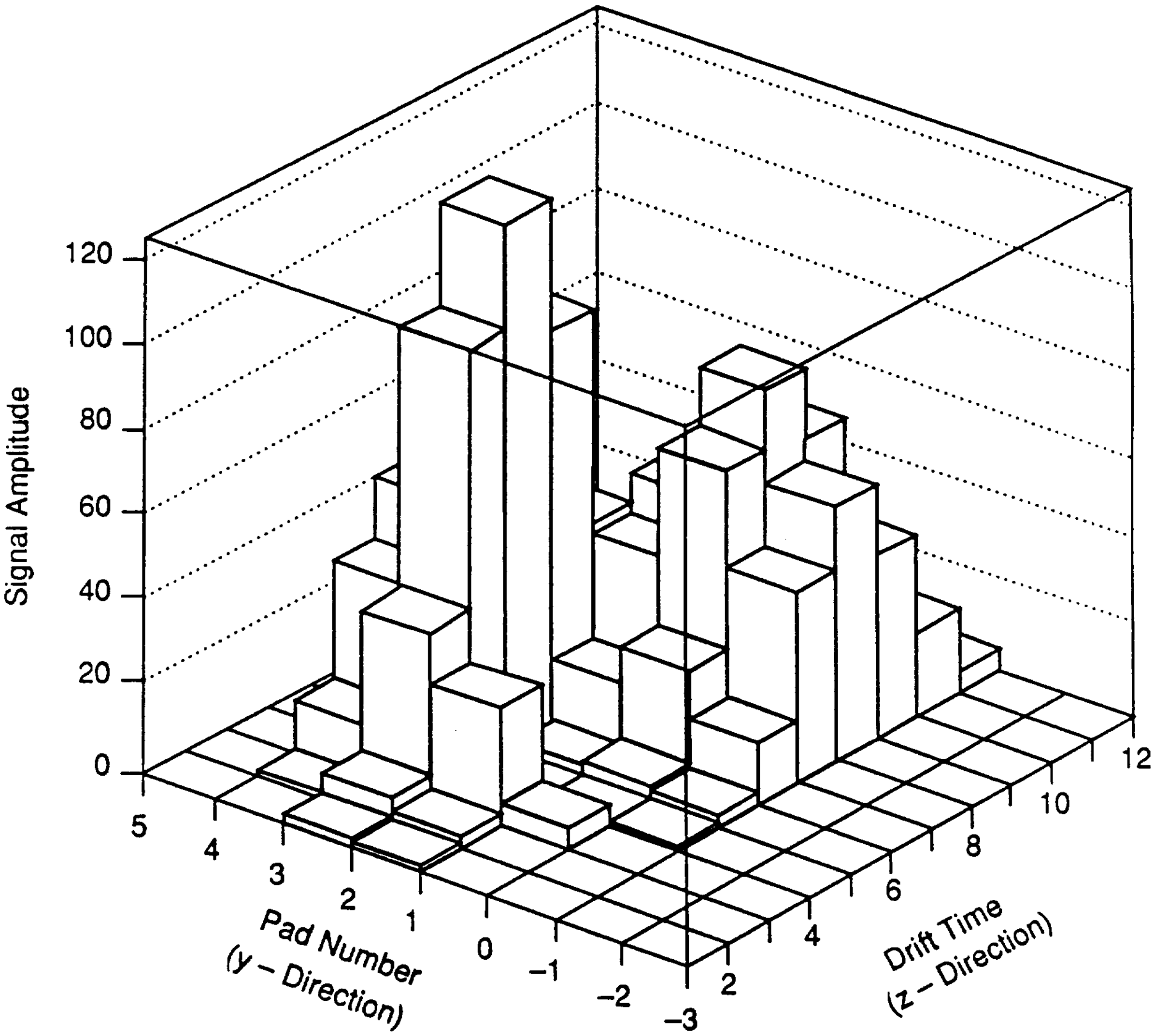

Signal Amplitude
120
100
80
60
40
20
0
5
4
3
2
1
0
−1
−2
−3
Pad Number
(y − Direction)
2
4
6
8
10
12
Drift Time
(z − Direction)

Fig. 1c

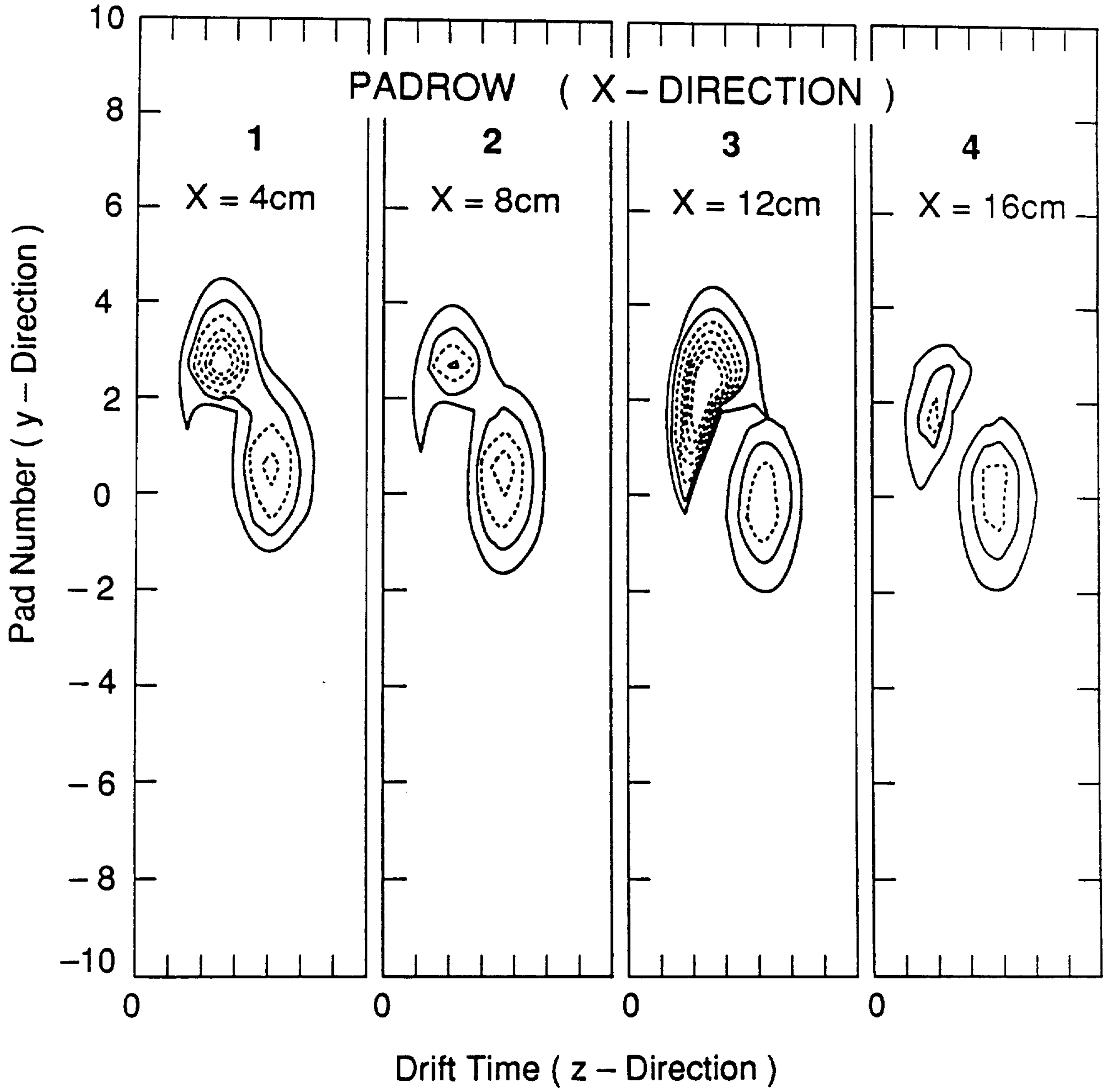
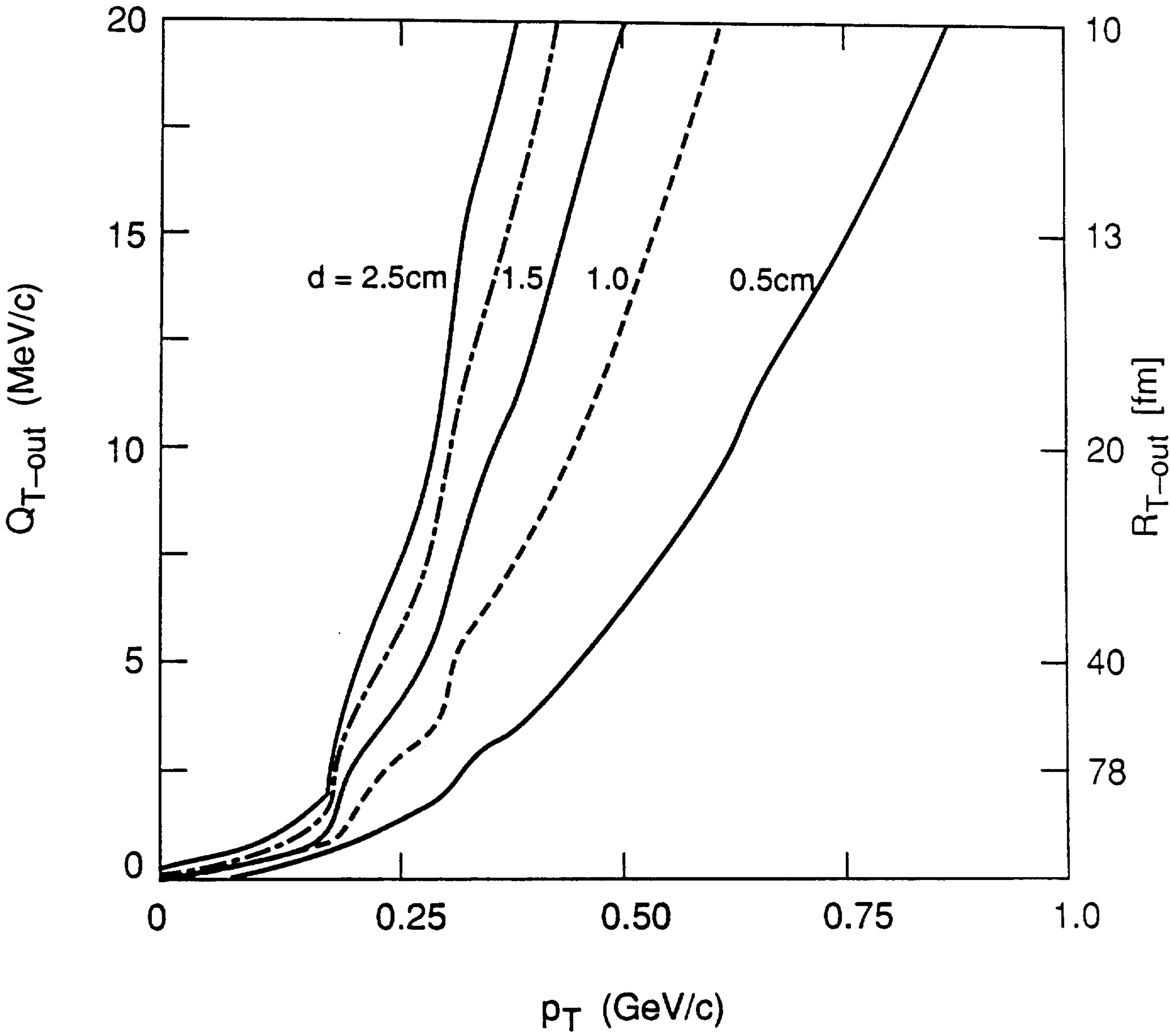
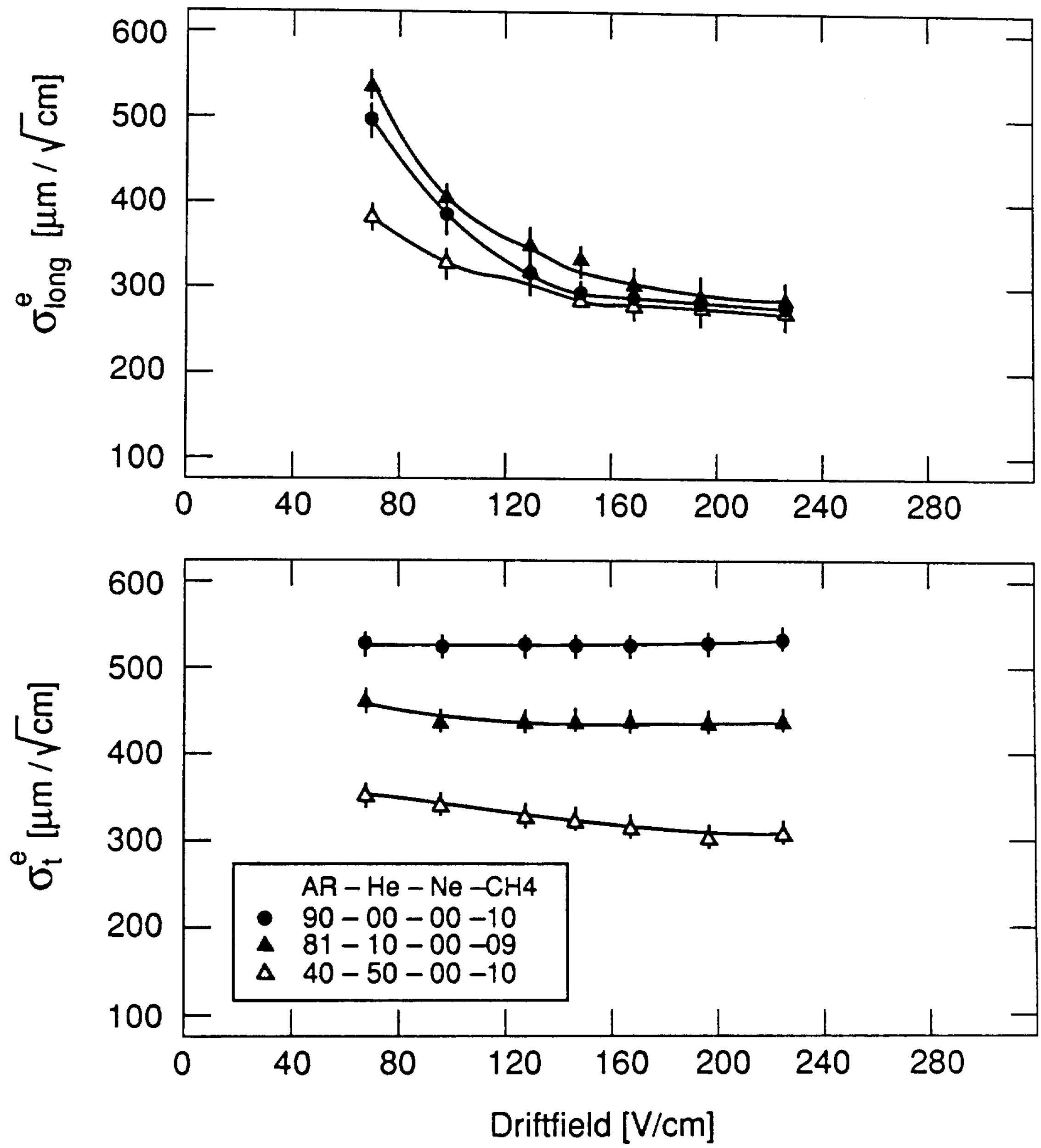

PADROW (X – DIRECTION)
1
X = 4cm
2
X = 8cm
3
X = 12cm
4
X = 16cm
Pad Number (y – Direction)
10
8
6
4
2
0
– 2
– 4
– 6
– 8
–10
0
0
0
0
Drift Time (z – Direction)

Fig. 1d



20
15
10
5
0
Q_{T-out} (MeV/c)
10
13
20
40
78
R_{T-out} [fm]
d = 2.5cm
1.5
1.0
0.5cm
0
0.25
0.50
0.75
1.0
p_T (GeV/c)

Fig. 2



600
500
400
300
200
100
σ^e_{long} [µm / √cm]
0
40
80
120
160
200
240
280
600
500
400
300
200
100
σ^e_t [µm / √cm]
AR – He – Ne –CH4
90 – 00 – 00 –10
81 – 10 – 00 –09
40 – 50 – 00 –10
0
40
80
120
160
200
240
280
Driftfield [V/cm]

Fig. 3

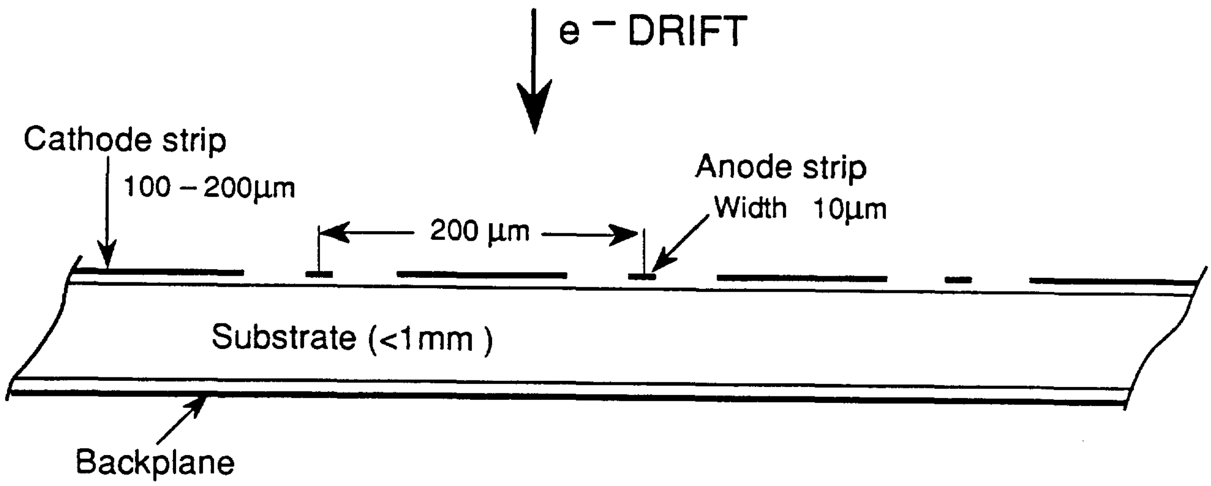

e − DRIFT
Cathode strip
100 – 200µm
Anode strip
Width 10µm
200 µm
Substrate (<1mm)
Backplane

Fig. 4a

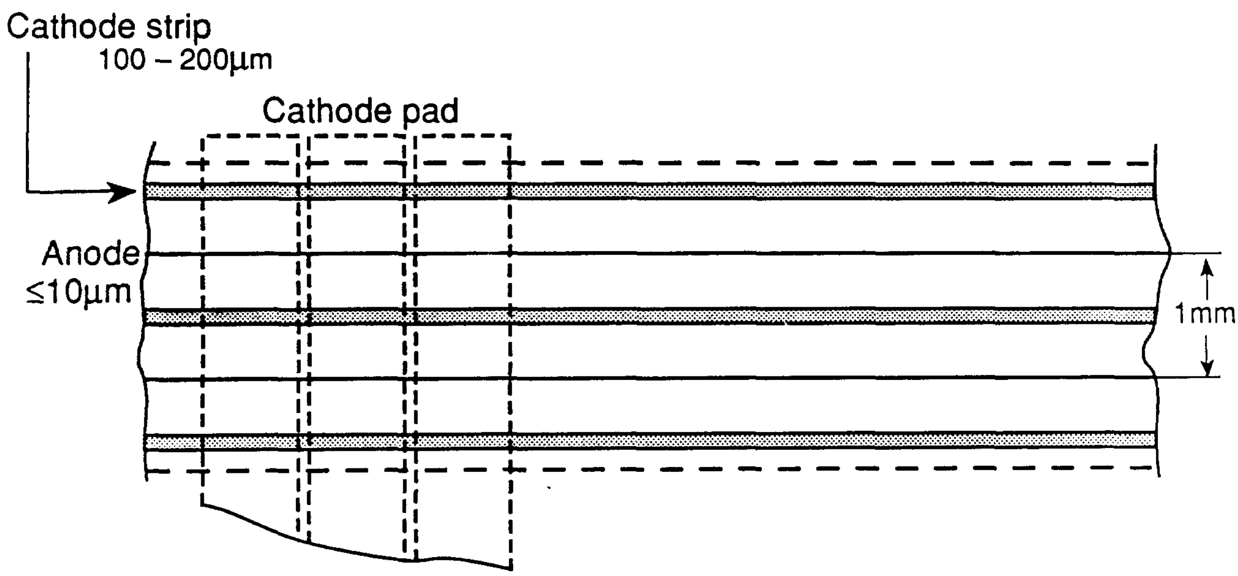

Cathode strip
100 – 200µm
Cathode pad
Anode
≤10µm
1mm

Fig. 4b

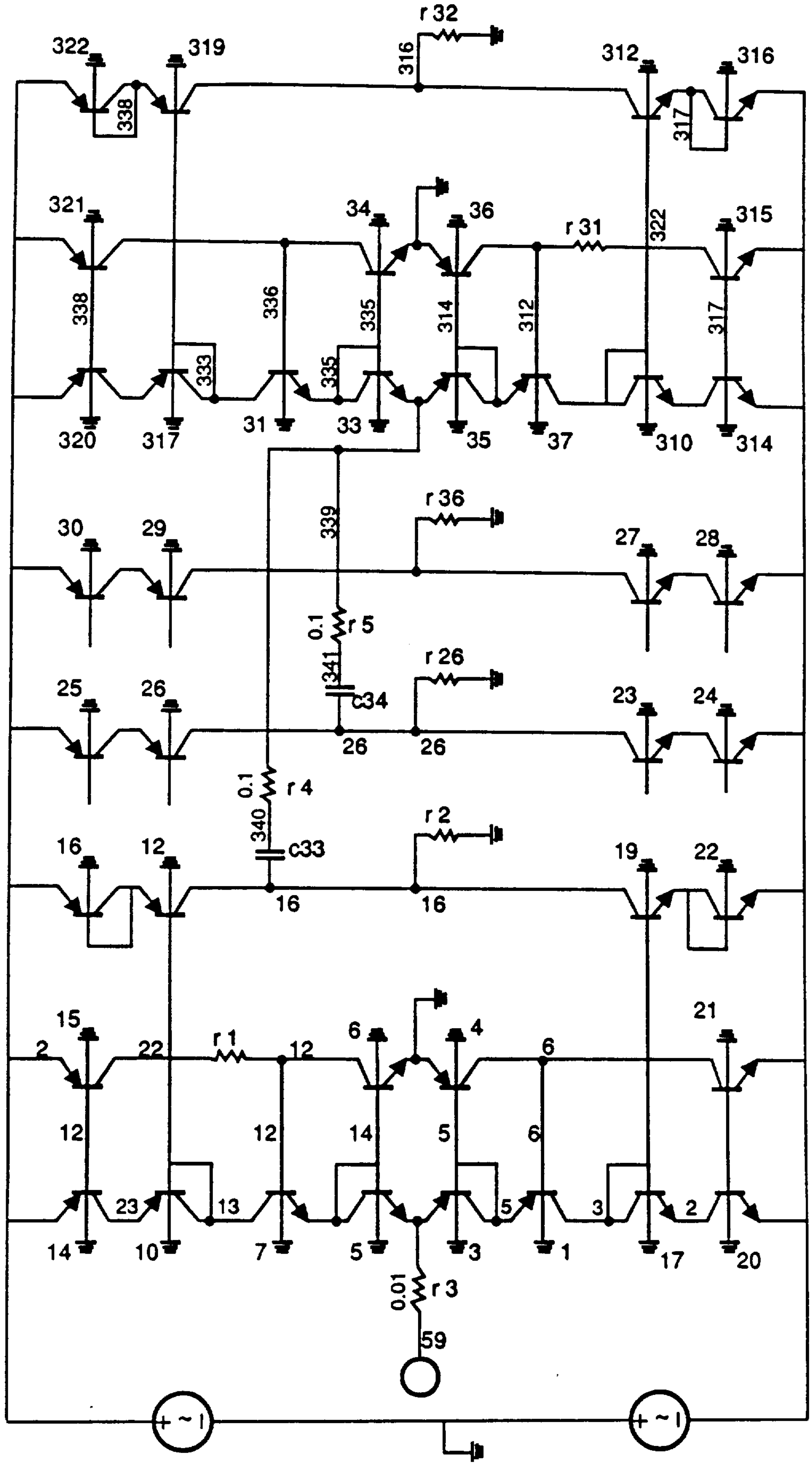


Fig. 5

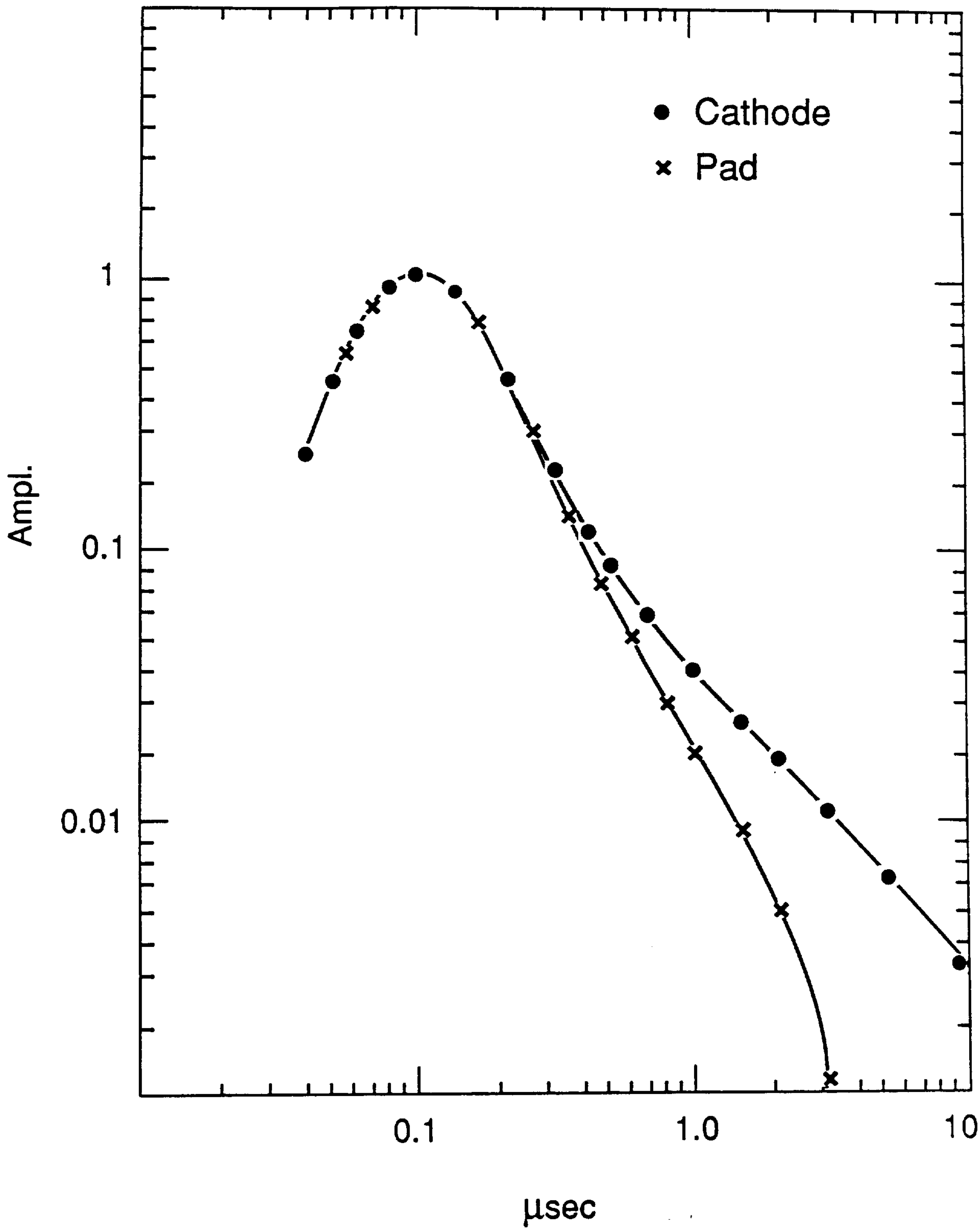


Fig. 6

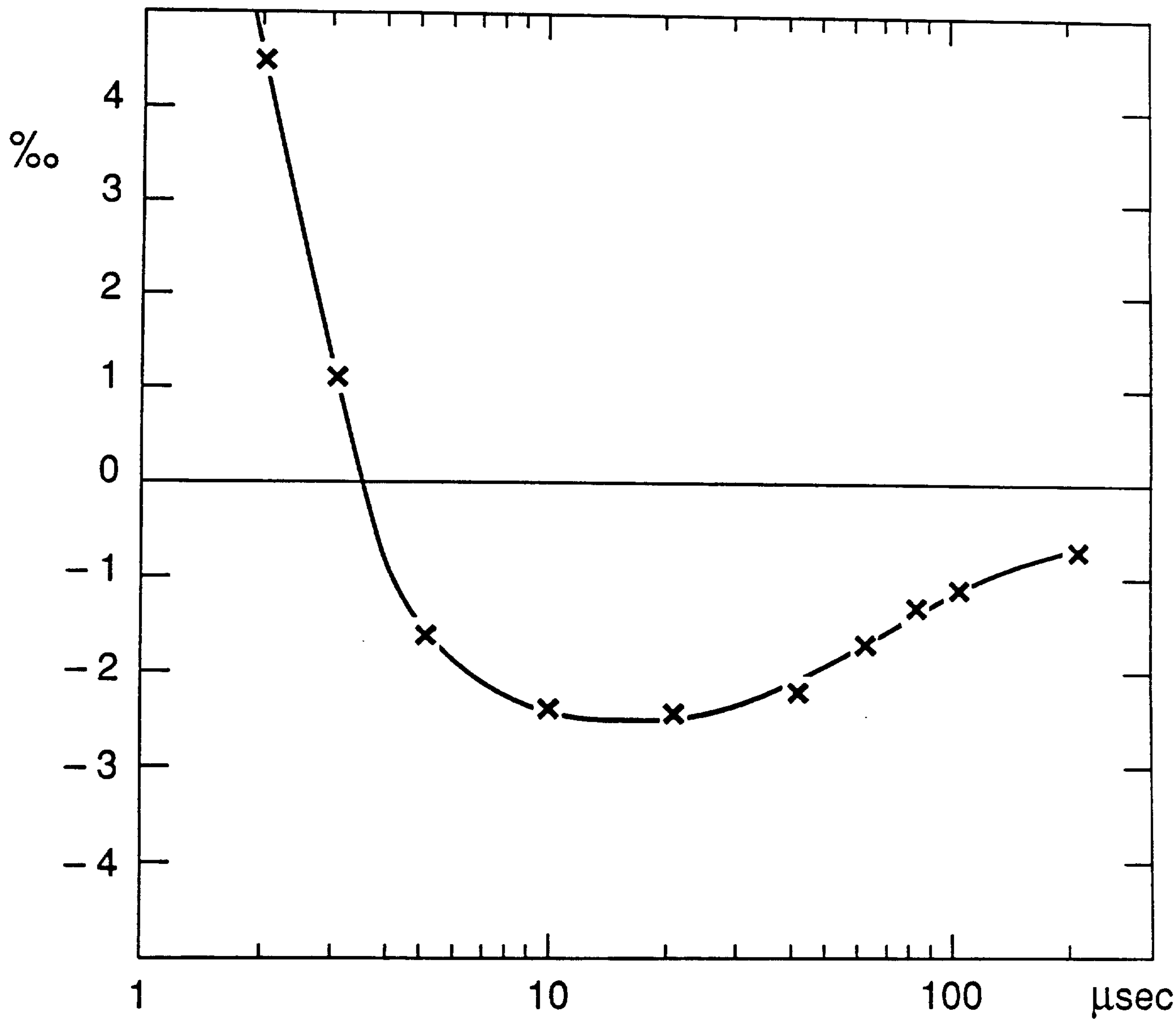


Fig. 7

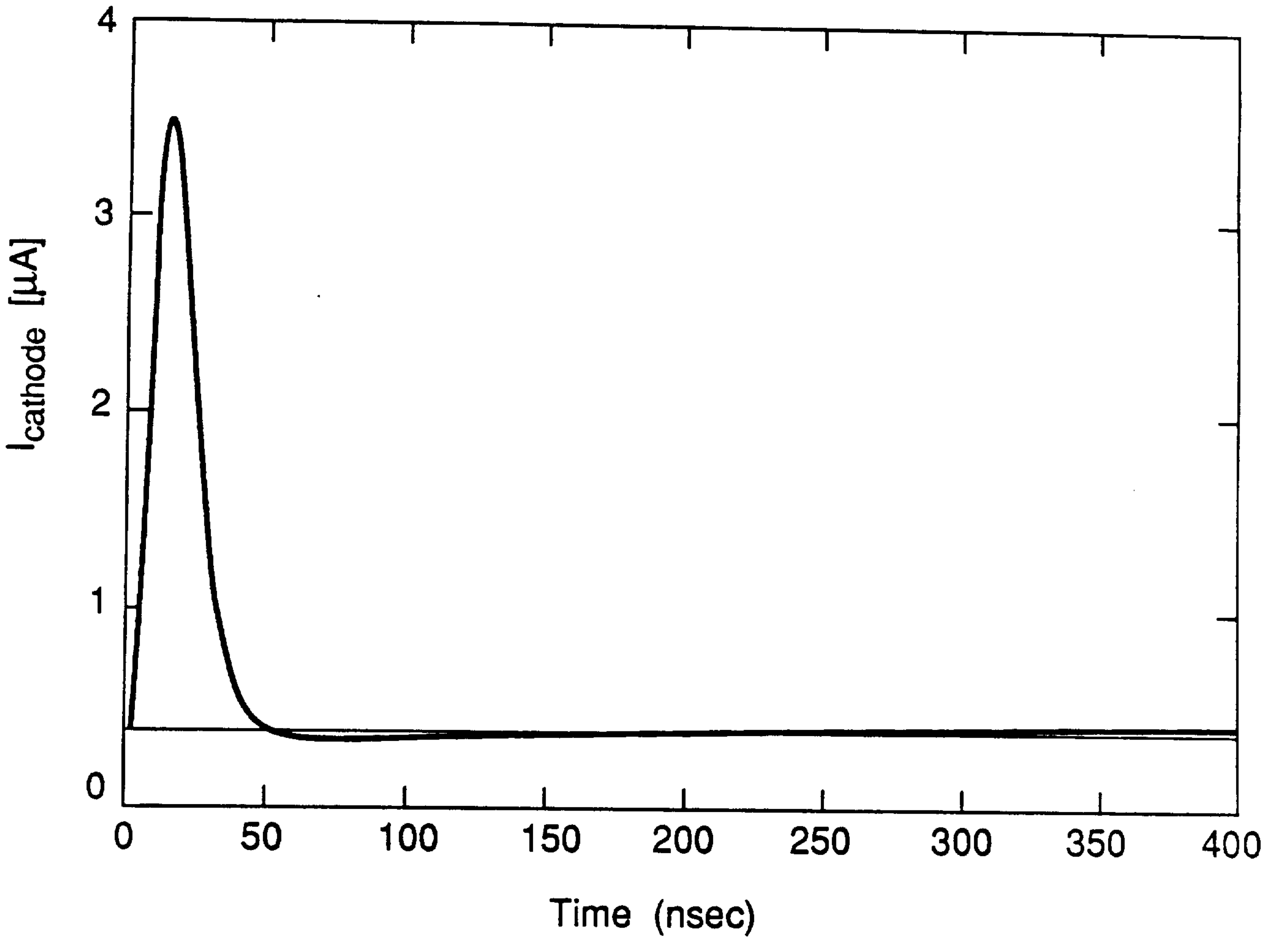


Fig. 8

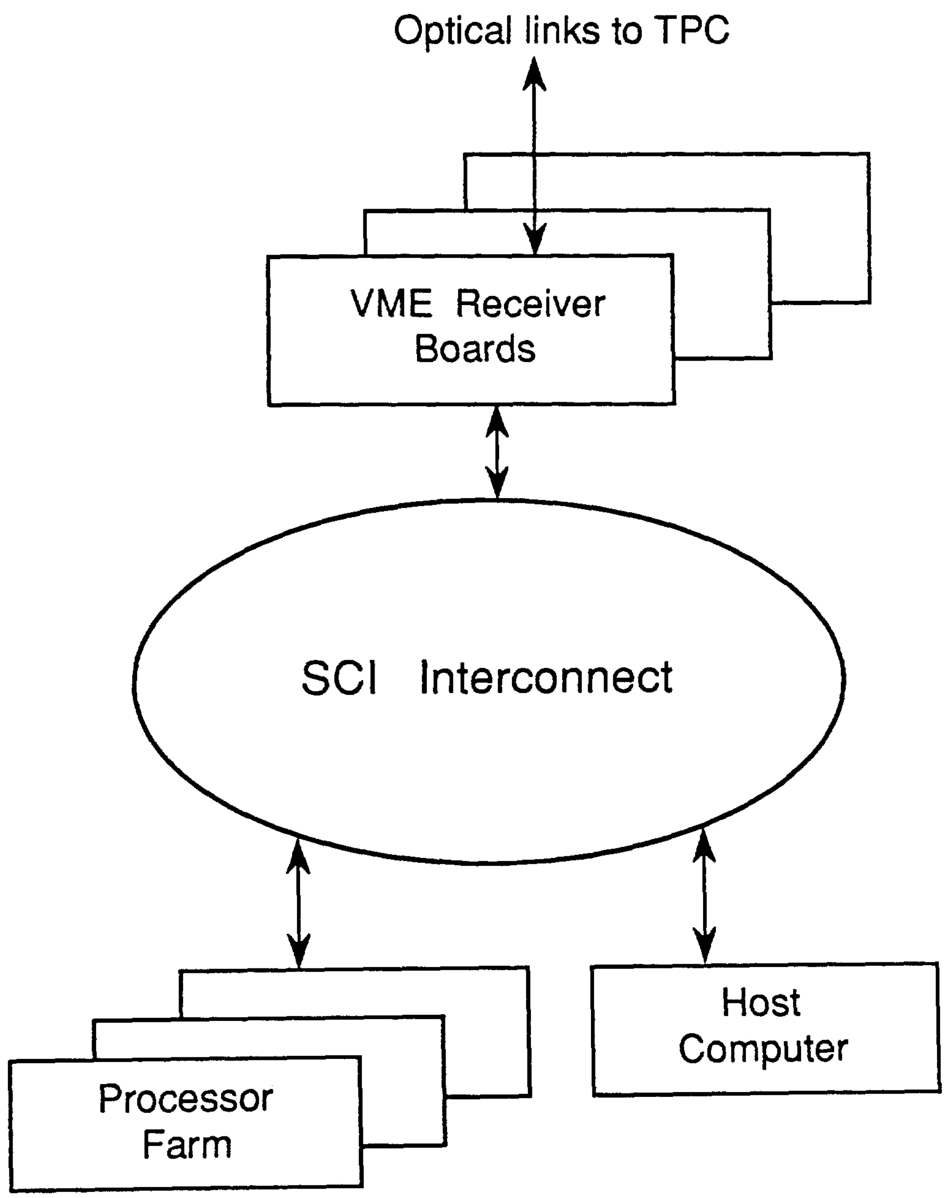

Optical links to TPC
VME Receiver Boards
SCI Interconnect
Processor Farm
Host Computer

Fig. 9