

Presented at the Oxford Conference  
on Computer Scanning  
April 2-5, 1974

CERN/D.Ph.II/INSTR 74-5  
(DD/74-15)  
7.5.1974

DESCRIPTION AND STATUS REPORT OF THE ERASME SYSTEM

ERASME Group

CERN, Geneva

Presented by J-C, Gouache

ABSTRACT

A general report is given of the ERASME system. ERASME has been developed at CERN for the analysis of film from the Big European Bubble Chamber BEBC. It is a system where the scanning of the film for interesting events, pre-digitizing, automatic measurement with a precision CRT, geometrical reconstruction and the rescue of failed events, have been incorporated into a single system.

Five scanning and measuring units, each controlled by a mini-computer will be eventually connected to a central medium size computer which has overall control of the whole system.

JCG/jr

1. INTRODUCTION

The concept of the ERASME system (Electron RAY Scanning and Measuring Equipment) contains no single novel approach to the problem of processing bubble chamber events (ref. 1). Its originality is rather that it represents the fusion of a number of ideas, to be found in such systems as POLLY and PEPR (ref. 2), with that of integrating into a single, self-contained facility the traditionally independent steps of scanning, measuring, spatial reconstruction and remeasurement. This integration has been motivated by the necessity to bring together as conveniently as possible, for the processing of the difficult film from the large chambers, many of the most effective techniques currently available. Combined in ERASME are : a high speed, random access measuring system, direct intervention by an operator to correct errors and on-line geometry as a means of checking the quality of the measurements. Integration also comes from a wish at CERN to simplify and rationalize the operation and maintenance of its bubble chamber event processing facilities, by reducing the number of steps and different types of machines employed.

It is not intended that this paper should give a detailed description of ERASME hardware and software. Instead it will attempt first of all in Section 2, to outline the hardware and at the same time bring out its more interesting features. Section 3 describes the software and its structure against the background of how a typical event is measured. In Section 4, something of the project's progress and current status is given. The current performance of the system is presented in Section 5. In particular, results are given on the calibration of the Scanning and Measuring (S/M) Units and on the measurement of events in the 2 m. chamber and BEBC.

The last section presents a new development in the ERASME project, that of a micro-processor aimed at speeding up the analysis of the raw data during the measurement of a picture.

2. HIGHLIGHTS OF THE HARDWARE

2.1. General

Fig. 1 shows the layout of the elements of the ERASME system. It will ultimately consist of five or six Scanning and Measuring units each with its own control computer (PDP-11) connected by a fast parallel link to a medium size computer (PDP-10) dedicated to the project.

Each S/M unit is made up of the following parts (Fig.2) :

- the main mechanical structure
- several optical systems
- the precision CRT and track detection units
- the digitizing logic and scan control
- the interface to the PDP-11
- the film transport system
- the stage and film transport controls
- the operator's table carrying two storage displays, function and alphanumeric keyboards and a track-ball

Each S/M unit can be considered as two almost independent machines, one for measuring, one for scanning. Any one of up to four views can be presented to either of these "machines" or so-called channels by moving the lower stage. This stage carries five gates; four are for films (corresponding to the chamber views) and a fifth is used for calibration grids. In order to avoid having to calibrate each individual film gate, this lower stage must move in a very precise and reproducible way. It is adjusted so that any vertical displacements of the gates along the axis of the measuring channel, lie within  $\pm 15\mu\text{m}$ . In this way an S/M-unit can be fully calibrated by measuring a grid in the fifth channel. Fig. 3 shows an artist's impression of the optical and mechanical parts. Fig. 4 shows a general view of an S/M-unit. Table 1 gives further information on the parameters of the S/M-units.

## 2.2 The projection channel

The light source is a 400W halogen lamp located at the focus of a parabolic reflector. From this the parallel light goes through a Fresnel condenser lens and then traverses the film on the lower stage. The light next passes through the projection lenses carried by a small X-Y stage. Two magnifications are provided (x 17 and x 35); the change of magnification is performed by a movement of the Y-stage. After reflection on two mirrors the light falls onto the operator's table where a fixed cross is also projected. The operator can steer the movement of the projected image by means of a track-ball which controls the displacement of the X-Y stages. Thus by moving the image of an event to align various of its features (vertices, end-points, etc.) with the cross and by recording the positions of the X-Y stages, the operator can provide all the information needed for pre-measurement or for rescuing especially difficult events.

## 2.3 The Measuring Channel

### 2.3.1 Precision CRT and Track Detection Units

A block diagram of these units is shown in fig. 5. The CRT is a Ferranti, 7 inch, Microspot tube, with an A-phosphor, using magnetic focussing and deflection. The mechanical mount for this CRT has been carefully designed, to facilitate the precise alignment of the coils and to give good rigidity with long term stability.

Dynamic focus and astigmatism correction is used to maintain the spot's diameter to  $15 \pm 0.7\mu\text{m}$  (at 50% intensity), over the whole scanning area of the screen. The necessary correction currents are provided by the spot shape control (SSC) unit (ref. 3). The values for the optimum correction at 81 points are stored in 9 x 9 matrices of potentiometers. Linear interpolation is then used between these values to derive the correction currents. The deflection coil is designed to have a very low residual magnetism of 0.005%. The effect of the remaining hysteresis has been further reduced

to the level of one least count (1/65,536) by moving the spot, by program, through standard cycles in between slice scans. (see 5.1).

The position of the light spot on the CRT is defined at any moment by the contents of the deflection counters in the scan control unit. Very precise 16-bit digital to analogue converters (DAC) (ref.4) in the deflection control unit convert the digitally defined positions into voltages which are inputs for the deflection drivers. These are highly stable voltage-current converters that control the currents in the deflection coils.

An image of the spot on the screen of the CRT is focussed, by a large aperture high precision Zeiss lens, onto the film with a demagnification of 1:0.8. The light which traverses the film is projected by a condenser lens onto the surface of a photomultiplier. The signal from this photomultiplier is treated in the video processing unit (fig. 6). Inputs from four reference photomultipliers are used to compensate for the variations of the light output of the screen phosphor (ref. 5). In the video processing and track detector units a special effort has been made to optimise the signal to noise ratio and to detect tracks of very small contrast on largely varying film backgrounds. Control by the PDP-11 is provided for :

- filter  $(\sin)^2$  selection
- photomultiplier gain
- bright field/dark field-film selection
- pulse width limits
- discriminator level.

Track pulses that exceed the discriminator threshold are normalized and passed on to the digitizing logic.

### 2.3.2 The Scan Control and Digitizing Logic

The basic scan pattern used in ERASME is shown in fig.7. This so-called "Slice Scan" can be oriented in any direction and its origin located anywhere

on the screen. The motion of the spot along each scan line is usually set to be approximately perpendicular to the track to be measured.

The scan is generated entirely by digital hardware, and all the parameters shown on fig. 7 are under computer control. The scan pattern is made using synchronous logic driven by a 20 MHz clock, and the track coordinates are normally given as the number of clock-pulses elapsed from the start of a given line; in other words the system works in a local coordinate system which is oriented in the direction of the slice scan (ref. 6). By means of the appropriate computer commands, it is equally feasible to work in an absolute coordinate system where the scan lines are parallel to one of the deflection axes, and the origin is fixed.

The deflection, flyback and blanking of the spot are also timed by the Scan Control Logic. It derives the flyback settling time as a function of the scan lines length  $\Delta F$ , in order to minimize the time needed to execute a given slice scan.

The digitizing logic generates from the normalized track pulses, their width (W) and the distance (C) of their centres along the scan lines. W as well as C are usually transferred directly to the PDP-11's memory. The line number coordinate S may be read out at the end of each line, together with N, which is the number of track pulses recorded on that line; or alternatively S may be read out for each digitizing.

#### 2.4 The film transport system

This part of the S/M-units has been designed with the fact very much in mind that they are, in effect, four view scan tables, but with the added complication that the film gates have to be moved between the projection and measuring channels. In addition they have to work with either 50 mm unperforated film from the CERN 2m HBC or 70 mm perforated film from BEBC or Mirabelle and with reels containing up to 300 m of film.

For these reasons the film transport system has only a modest performance in speed. To move the film one frame takes about a second, quite adequate for the frame by frame advances used when scanning. The heavy reels are mounted on free standing units on either side of the main structure of the S/M-unit in order not to load unnecessarily the very precise lower stage. Between the reels and the film gates the film hangs in free loops to accommodate the motion of the lower stage.

## 2.5 Stage and film transport controls

The movement of all stages is controlled by a digital system under command of the PDP-11 (fig. 8). The X-Y stages are driven by a velocity servo system, where the input is taken from an up-down counter. The contents of this velocity counter are always changed at constant frequency to keep the maximum acceleration of the motor constant. The position of each stage is held in a position counter. There is a distance counter, that can be preset by the computer to give an interrupt when a given distance has been travelled. Thus the PDP-11 can produce any desired movement of the stages by splitting it into a series of well-defined elementary actions. In another mode of operation, the positions of the X-Y stages can be controlled in a non-linear manner from the track ball. The lower stage is controlled by a similar system, but without the position servo loop.

The film transport control has to maintain free hanging loops of a constant length between the reels and the film gates; thus for each view three capstans have to be synchronised: one on the lower stage and one for each of the two film reels. This synchronisation is assured by sets of cams and microswitches for perforated film and by Brenner mark detectors for unperforated film. The displacement of the desired number of frames is obtained by counting in the PDP-11 the interrupts coming either from the microswitches or from the Brenner mark detectors. For both forward and backward movements two velocities are provided : a 'high' velocity of 26 cm/s and a 'low' velocity of 7 cm/s. Independent of the direction of the requested displacement, the film transport is programmed to always

arrive at its destination after a final movement forward at low speed in order to obtain the desired stopping accuracy.

## 2.6 Computer System

The central computer of the ERASME system is a PDP-10, its main components at present are a KA-10 central processor, 160 K 36-bit word core memory, three 25-megabyte disk pack drives and two magnetic tape units (fig. 1). In May 1974 as foreseen, this configuration will be upgraded by exchanging the present processor for a KI-10 central processor and extending the memory size to 256 K words. The minicomputers dedicated to each S/M-unit are either PDP-11/20's or /45's each with 8K 16-bit word memories, but without standard peripherals of their own.

The PDP-11's are connected to the PDP-10 through interfaces which have been designed to meet the specific needs of the ERASME system (ref.7). Through these interfaces the PDP-11's use the address space of their UNIBUS' to directly access the PDP-10 memory. The address mapping is illustrated in fig. 9. Each interface responds to two ranges of UNIBUS addresses (called windows). The sizes of the windows and their positions in the PDP-10 memory are defined by two independent registers for each PDP-11. In this way the two memory windows for each PDP-11 can be set independently to point to arbitrary PDP-10 memory areas.

One of the two windows, called the Data Communication Area (DCA), appears to the PDP-11 as normal read/write memory whereas the second appears as a read only memory and is called the Common Code Area (CCA).

For inter-processor communication the PDP-10 can send interrupt requests to each PDP-11 on any of the four Bus Request levels and for any vector address 0 to 774. The PDP-11 can also send interrupt requests to the PDP-10 on any of its seven levels.

Besides supporting the S/M-units when they are running for production



or testing, the PDP-10 simultaneously provides a general time sharing service for the programmers of the project via some eight terminals. The disk file storage is used to keep not only the system software but also those programs and data files that the programmers are using for their work as well as the accumulated production output data.

3. ERASME SOFTWARE

3.1 The Processing of an event

The ERASME system of software has been designed, so as to allow the user to choose freely for each S/M-unit its mode of operation, e.g., predigitized film, scanning with or without the help of geometrical processors, complete geometrical reconstruction on-line or only track-match and topology tests. Only one mode of operation is described here (fig. 10), that where the film is : scanned for interesting events, predigitized, automatically measured with the CRT, geometrically reconstructed and events failing the reconstruction are rescued on-line. This one pass system avoids the painful remeasurement of failed events as a separate phase with all the associated bookkeeping and unnecessary data-handling.

The scan phase is essentially the same as on conventional scan tables. However, as each S/M-unit has effectively its own rough and precise measuring facilities and is on-line to a medium sized computer, geometrical and kinematic processors could be used to assist the scanning and even to apply selection criteria. Having found an interesting event the operator starts indicating the vertices and gives auxiliary points where appropriate (such as stop, end, crutch\* and anticrutch points\*\*).

---

\* A crutch point is an additional point measured by the operator in an unobscured region of a track that he knows the programs are unlikely to find successfully.

\*\* An anti-crutch point is used to indicate a track that must not be measured, e.g. to eliminate a beam track that could be confused with the one really to be measured.

In general he does not need to measure a fiducial. For extremely difficult tracks he can even give two or more points per track to define a curve along which the track gets measured precisely. When the operator has finished all of the measurements on the optical projection of a view, it is moved into the measurement channel and all of these preliminary measurements are transformed into the distorted coordinate system of the CRT-channel. The fiducial program first of all tries to find one reference fiducial in a fairly large search region. When this is found the positions of all the others can be predicted fairly accurately. Each fiducial mark is measured by making only one slice scan with scan lines approximately bisecting the largest angle between the fiducial arms. A histogram is made for both arms and a linear fit is made through the digitizings in the nearest pulse to the prediction. A new histogram is then made at an improved angle, followed by a final fit (second order if appropriate) and then the intersection calculated.

Having finished measuring the fiducials, the program proceeds to measure the tracks. Around the vertex position, roughly known from measurement in the optical projection or a prediction, tracks are searched for using a pattern of very narrow slice scan in the form of partial octogon pairs (fig. 11a). The scan lines are parallel to the sides of the octogons. The digitizings from these slices scans are then histogrammed and master points are calculated. Close master points in pairs of octogons are then considered to be possible track candidates, if they define a direction pointing roughly to the vertex. In this case, track following towards the vertex is started. Only when the track comes relatively close to the vertex, is the track also followed outwards. We are convinced, that a very high percentage of track segments are very easy to follow and do not need very sophisticated software, in particular, floating point arithmetic. A track segment is defined here as a piece of track that a simple track following program can follow until it is stopped either by reaching a given end point or by finding no more master points. The latter case occurs at the end of the track or if the track follower has made an erroneous prediction because of a wrong point. In either case the last points are thrown away. A circular least squares

fit is then made through the last good points to extrapolate beyond the dropped points and the track follower is re-initialised. With this restart feature a lot of tracks are saved and the end of the tracks are better defined. This relatively simple track follower is nevertheless able to follow curved tracks through any angle. A maximum turning angle and track length is however imposed to avoid loops.

After a complete track is followed, an attempt is made to match to it, stop, end, crutch and anticrutch points and charged vees. Attempts are also made to remove bad points and to find kinks. When a charged vee, stop or end point is matched or a kink is detected, the track is cut at that place. When an anticrutch point is matched, the whole track is deleted, but the track parameters are kept, so that the track is not re-initialised. If after all tracks have been followed, there remain any unmatched points, the program tries to initialise tracks from these points without making any assumptions about the direction of the tracks (full octogon searches).

Having finished track following, an effort is made to eliminate identical tracks by sliding a parabola along one track and checking its separation from other tracks with approximately the same azimuth angle at the vertex. With the remaining tracks the program tries to improve the vertex position. The intersection points of circles fitted through the vertex end of the tracks are put into classes on the basis of their relative separations. The new vertex is then calculated as the average point of the class which includes the manual measurement of the vertex. The distances of all tracks from this vertex are again checked and all of those that are too far away are rejected.

The surviving tracks are now shown to the operator on a display (fig. 11b). He can decide to add 'un-found' tracks by giving crutch points, or give additional points on existing tracks, or to delete complete tracks or single points on tracks. At any time, he can request displays at various magnifications in which the tracks are seen plotted on top of the digitisings.

These procedures are repeated for all vertices in a view and for all views, at the end of which the event is presented to the on-line geometry processors, which perform the reconstruction of the event. It is possible that this online reconstruction may not be necessary for many experiments in the 2 m chamber. However, it will be vital for experiments in BEBC with beams from the SPS.

### 3.2 Brief outline of the software structure

The ERASME software is implemented in a flexible and modular way using the HYDRA-system (ref. 8) and in particular its management of the dynamic store. Logical program units like scanning, track finding, track matching etc. are processors communicating with each other via the dynamic store, thus guaranteeing re-entrancy at the processor level. Individual S/M-units make use of these processors. Individual processors may either be uniquely used by a specific S/M-unit or shared by several, in which case, it is steered by data corresponding to the unit. For convenience, associated processors are grouped together into jobs. Some of the advantages of this structure, is that it allows economies in the use of memory by sharing processors and it facilitates program modification. Each S/M-unit has a core resident segment that is used for its communication between jobs and processors (see fig. 12).

The software is split between the PDP-11 and the PDP-10, the programs residing in the PDP-10 having the overall control of the scanning, measuring, reconstruction and rescuing sequence. This sequence can be different for each S/M-unit and can be influenced by their operators. The PDP-11's perform tasks at the request of programs in the central computer. These tasks vary from very simple ones like selecting a discriminator level to complex ones like a track follower. As all of the CPU time consuming pattern recognition tasks can fortunately be done in distorted CRT-coordinate space, they can be performed by the PDP-11 without the use of floating point hardware. Furthermore, all plots of digitizings are done directly from buffers in the PDP-11's memory, so in no circumstances do digitizings

ever have to be transmitted to the PDP-10. This avoids interrupting the central computer at too frequent intervals and greatly reduces the data that has to be transferred between the computers.

4. STATUS

The project was approved and started officially towards the end of 1970. The first S/M-unit was completed in May 1972. This first unit has been used to develop and improve the necessary software, to assess the quality of the measurements and to train the operating staff. Until now S/M-1 has measured 10,750 events of a  $K^+p$  experiment in the CERN 2m hydrogen bubble chamber at 16 GeV/c (previously measured on HPD) and 2,500 events of another  $K^+p$  experiment at 4.2 GeV/c (previously measured on the CERN Spiral Readers). At present S/M-1 is being used for testing the incorporation of the on-line geometry program into the production software. This task should come to an end in the next few months.

In the meantime, the second unit (S/M-2) was completed in April 1973. It has been mainly used for work on the problems connected with large chamber photographs and to develop the necessary software for the analysis of BEBC pictures. The main difficulty has been to detect the low contrast track images against a non-uniform grey background. This led to the development of an automatic gain control system for the track photomultiplier (ref. 5). Moreover, in order to cope with variations in the contrast of the track images and permanent features of the background, which give video signals similar to those from tracks, the PDP-11 controls the discrimination threshold according to a map of the background. Up until now S/M-2 has measured about 1,300 BEBC events, mainly  $V_0$  events, in order to assess the precision of the chamber and to investigate the distortions. S/M-2 has also been used to produce titles for BEBC, to compare film qualities from different manufacturers and to start the training of the operators on the scanning and measuring of BEBC pictures.

During 1973 a series of modifications were introduced in the mechanical

design, so that the later S/M-units will also be able to fully handle 50 mm unperforated film from the CERN 2 m HBC. The film gates' maximum aperture was increased from 106 mm to 124 mm, the film transport was modified and equipped with Brenner mark detectors and the light source was redesigned to illuminate a larger circle in the film plane. Several simplifications arising from our experience with the first two S/M-units have also been introduced. They are : shortening of the optical path and the suppression of one mirror, using a casting for the lower stage and the complete redesign of the objective stages.

The completion of S/M-3 has been delayed because of a major problem with its CRT, that appeared during its final tests.

The construction of S/M-4 and S/M-5 is progressing on schedule. The digital electronics for S/M-4 have already been tested, the mechanics and electro-mechanics are being assembled and the CRT mechanics and electronics are being mounted. In the last few weeks the mechanical parts for S/M-5 have been delivered and the tests of the digital electronics have already started.

## 5. RESULTS AND PERFORMANCE

### 5.1 Hardware Tests

In a CRT system many parameters of the scan are varied, such as : the discriminator level, the orientation of the scan slice and the position inside the slice of the object to be measured ; therefore checks must be made to see that such variations do not introduce appreciable errors. The checks consist of measuring the position of a cross or a line on a calibration grid, then changing one of these parameters and measuring the position of the object again. The difference between the two positions is an estimate of the error introduced by changing that parameter. All effects were checked regularly and found to be unimportant except the change in the orientation of the scan which can introduce errors as large as 4.5  $\mu\text{m}$ ; this last effect, however, can play a role only on low momentum

tracks where in any case the Coulomb scattering dominates.

The deflection coils of the CRT have a residual hysteresis (see 2.3.1) and the measured position of a point is affected by an error which changes according to the position from which the spot was moved to measure that point. These errors do not show any regular pattern over the measuring area and can be as large as 9  $\mu\text{m}$ . Clearly a calibration cannot help in this case; however, these errors can be eliminated by moving the spot in a fixed sequence over the boundaries of the measuring area prior to measurement. This procedure, which reduces the errors due to hysteresis to less than 1.5  $\mu\text{m}$ , takes about 150 msec; it is not possible to reduce this time without increasing the errors. At present this procedure is applied whenever a fiducial is measured or the spot was moved for more than 1/8 of the total length of the measuring area or no scan was made for more than 50 msec.

It is known that the spot needs some time to settle down to its final position after having been moved instantaneously over some distance. A typical example of the variation of this time with distance is shown in fig. 13. After each jump of the spot a scan is therefore not started before the appropriate time has elapsed. The dependence of this settling time on position is at present being investigated.

Super imposed on this is another type of settling phenomenon, with a large time constant of  $\sim 1$  sec. It is seen whenever the spot has been kept in a fixed region for some seconds prior to the jump. In order to minimize this effect, which is proportional to the length of the jump, the spot is normally "parked" in the middle of the screen. As, normally, measuring times are short, tracks, fiducials and calibration measurement are done at the beginning of this settling period as a consequence the error introduced is negligible. If however, a measurement would take a long time (i.e.,  $\sim 1$  sec.), an error as large as 5  $\mu\text{m}$  could be introduced for large spot movements.

## 5.2 Calibration of the Measuring Channel

A calibration is performed every day on each S/M-unit. To do this

a glass calibration grid mounted in the fifth gate, is brought into the measuring channel and 200 crosses are measured, the position of each cross being known to better than  $\pm 1. \mu\text{m}$ . The transformation between the grid and the CRT coordinates, as obtained by fitting the known cross positions to the measured ones, is parametrized by a fifth order polynomial. A typical set of residuals from the fit is shown in fig. 14a,b. Their mean value is about  $1 \mu\text{m}$  and the maximum normally below  $3 \mu\text{m}$ .

In order to see whether individual calibrations would be necessary for each film gate, the same grid has been, in turn, put in each of the four gates and measured. In fig. 15a,b, two sets of residuals are compared for each gate. The first ones are obtained from a fifth order polynomial fit for each gate, whereas the others are obtained, apart from a linear adjustment, by using the transformation determined for the fifth gate. The residuals of the second set are, on average,  $\sim 1 \mu\text{m}$  larger. This is considered to be tolerable.

In order to see how frequently a calibration is needed, the method of comparison just described has been applied to a set of calibration measurements taken over a three week period. From fig. 16 one can see that using the same transformation over three weeks, the residuals do not increase on average by more than  $0.5 \mu\text{m}$ . However, as a calibration requires only a few minutes, it was considered safer to recalibrate once a day.

### 5.3 Measurements of Events from the CERN 2 metre Hydrogen Chamber

The performance of a system can be seriously assessed only after a period of real production and this is not yet the case for ERASME. The tests performed up to now on events from the CERN 2 metre Hydrogen Chamber, however, seem to us encouraging enough to be worth mentioning.

The results presented here are based on 5,300  $K^-p$  interactions at  $16 \text{ GeV}/c$ , already measured on the CERN HPDII, which were processed on the



first ERASME unit.

As the first two S/M-units were designed to process only film from the giant bubble chambers, one had to accept a 25% reduction in the length of the chamber's visible volume, due to insufficient film gate aperture. In addition, a provisional film transport not under computer control was in use, so the operators were somewhat slowed down by the fact that they had to read and type in frame numbers. Both of these limitations will not be present when the production of 2 m HBC events starts on the third unit.

The operator had to find the events, predigitize the vertices and get the measurements done. In order to ease the comparison with the HPD results, he was supplied with "frame guidance", i.e., a list of frame numbers and topologies of the relevant events. All topologies, except the ones with charged decays, were measured.

On-line geometry was not yet available at that time, so that the operator only intervened on the basis of information from the pattern recognition program.

#### Pass rate

A detailed analysis of the rejects indicates that when rescuing after the on-line geometric reconstruction of the events is implemented, a pass rate will be obtained that is better than 95%. For these tests, however, the overall pass rate after off-line geometry and kinematic analysis was of 77% to 85% for 2 pronged events, 75% for 4 prongs and 71% for the other topologies.

#### Measuring precision

Due to the film gate aperture limitation a portion of the chamber, at the beam entrance side, was not available for measurements. As a consequence, the lengths of beam tracks measured by S/M-1 were, on average, 40 cm shorter than those measured by the HPD. On the other hand, the secondary tracks were unaffected. As our aim was to make a comparison between

S/M-1 and the HPD that was independent of this limitation, only the  $V^0$  decays were used to compare the widths of invariant mass distributions obtained from the two machines. In fig. 17,a,c, the invariant mass squared for 252  $K^0$  and 119  $\Lambda$  particles are shown. The average momentum of the  $K^0$  was 8 GeV/c and of the  $\Lambda^0$ , 1 GeV/c. One can see that the central values agree to within one standard deviation. The widths of the  $K^0$  distributions obtained from S/M-1 and HPD (fig. 17,b,d,) equal to within 15% ; the same is also true for the  $\Lambda^0$ , but this result is less significant than the previous one because the errors on the mass are dominated by multiple scattering.

Fig. 18, shows the average residuals, after geometric reconstruction, for a sample of 594 fast tracks ( $p > 10$  GeV/c) : their distribution peaks at around  $3\mu\text{m}$  on film and is almost the same for S/M-1 and the HPD.

In a search for systematic effects introduced by S/M-1, the pulls<sup>\*)</sup> have been calculated for 298 events which gave a 4-constraint fit to one of the two reactions :



The central values of these pull distributions are all compatible with zero, as they should be, except for the dip angle of the beam and the fast outgoing  $K^-$  track. This is reflected by an imbalance of  $12 \pm 2$  MeV/c in the z- component of the missing momentum, indicating the necessity to re-determine the bubble chamber's optical constants by measurements made on S/M-1 itself. For these tests, in fact, the optical constants used were ones determined from HPD measurements.

As a conclusion, although more detailed analysis is certainly needed, the data available indicate that ERASME has a measuring precision well comparable to that of the CERN HPD.

---

\*) The pull for a given quantity  $x$  is defined as

$$\text{pull } (x) = \frac{x_{\text{measured}} - x_{\text{fitted}}}{\sqrt{\frac{\sigma_{x_{\text{measured}}}^2}{2} + \frac{\sigma_{x_{\text{fitted}}}^2}{2}}}$$

### Speed

The only well trained operator available at the time processed, on average, 35 events per hour ( $\sim 100$  sec./event). The time actually taken by the CRT system was  $\sim 30$  sec./event. Due to the preliminary and rather "ad hoc" nature of these test measurements however, it is difficult to extrapolate these figures to real production conditions.

### 5.4 Measurements of BEBC Events

Fig. 19 shows a typical picture (9 GeV/c  $K^-$  run of November 1973). There are in average 13 beam tracks spread over about half of the beam window.

The determination of the optical constants for this new chamber has just started and the preliminary set of constants available certainly needs refinement. The distribution of the average residuals for 43 non-interacting beam tracks (fig. 20) peaks between 4 and 8  $\mu\text{m}$  on film, which would correspond to a "setting error" of  $\sim 350$   $\mu\text{m}$  in chamber space (magnification  $\approx \times 55$ ). It seems, however, that an appreciable fraction of the average residual is still due to systematic effects.

Up to now (March 1974) about 1,300  $K^-p$  interactions at 9 GeV/c have been scanned and measured on three views, using S/M-2 with an average scanning and measuring speed of 6 events/hour, two thirds of the time being spent in the measuring and rescue phases. The analysis of these events is under way.

## 6. MICROPROCESSOR

The master point of a slice scan is calculated from a set of three histograms which are generated in the local coordinate system of that scan. These are : number of hits per bin, the sum of the C-coordinates in each bin and the sum of the S-coordinates (or scan-line number) in each bin. A fourth histogram, namely the sum of the track widths in each bin is used as a quality factor in the master point evaluation.

In the present system the PDP-11 generates these four histograms from the 'raw' coordinates of each slice scan. The master point is then calculated

by taking the centre of gravity of the area of the highest peak above a given threshold. The most time consuming operation in this procedure is the generation of the four histograms : around 70% of the total master point calculation is spent on this repetitive operation which is obviously quite suitable for special hardware processing.

Different methods for implementing this were considered, varying from hard-wired systems using the PDP-11's own memory to the more flexible micro-coded more or less autonomous on-line processor. A solution has been adopted that takes full advantage of the recent developments in the field of integrated logic circuits, in particular the availability of medium sized, fast TTL static read/write memories and fast arithmetic units.

A 256 word 16 bit memory with 45 ns read or write access time was chosen to hold the four histograms. A relatively simple arithmetic unit with two accumulators was designed to update the histograms. The control is done by an instruction unit with a 256 word 48 bit memory. Both memories have their own arithmetic unit for address calculation. A simplified block diagram block of this processor is shown in fig. 21. To obtain the necessary speed of operation the processor was designed to execute several functions concurrently with a cycle time of 70 nsec. The three main units, the data unit, the arithmetic unit and the instruction unit, will normally all work at the same time, and the address calculations for the memory units overlap with the read or write of the previous cycle. A conditional skip or jump system makes four way branching on a single loop instruction possible. External quasi-interrupt flags are included to initiate a routine or signal the end of the incoming data to be processed.

In order to generate four histograms at high speed, the conventional method of calculating for each digitizing, a bin number by division in an arithmetic unit would be too slow. So the bin numbers are generated continuously in the digitizing logic. Whenever a digitizing is made a 7 bit number is placed in the most significant part of the 16 bit C-coordinate word, leaving 9 bits for the C-coordinate itself. This bin number is now

used directly as the address in the first histogram. Fixed offsets from this address give the addresses of the corresponding bins in the other histograms.

Once the histograms have been generated for a slice scan, the master point could be calculated in one of two ways. The first and simplest is to leave it to the PDP-11. Therefore, the micro-processor has a mode of operation where its data memory looks like part of the PDP-11's own memory. The other way is to do the necessary calculation in the processor, in which case full advantage can be taken from the high speed of the data memory. For this a multiply and divide unit has been designed and will be included in the processor.

Evidently, further tasks may be done in this processor, such as scaling and coordinate transformation for the on-line displays and execution of short routines. In this way the scanning and measuring processes could be made even more rapid.

#### 6.1 Software to Support the Micro-Processor

Because the hand programming of 48 bit instructions would be very labourious, all the micro-processor function have been defined in terms of 31 mnemonic operation codes (Op-codes). Complete 48 bit instructions are then made up from sets of these Op-codes. A cross-assembler running on the PDP-10 has been developed to enable programs written with these mnemonics to be directly assembled into micro-code. The assembler automatically checks for Op-code compatibility and looks for possible errors. Further software support has been provided for instruction loading, data I/O, processor control, and the debugging of both hardware and software via the PDP-11 control computer.

ACKNOWLEDGEMENTS

We would like to express our gratitude to Professor Ch. Peyrou, Drs. G.R. Macleod and M.G.N. Hine for their encouragement and support of the project.

The ERASME system is the result of the combined effort of many people; for this reason this paper is signed "ERASME Group". The list of people (draughtsmen, engineers, mechanics, physicists, programmers, and technicians) who have contributed to and participated in the development and construction of the project is as follows :

H. Anders	T. Lingjaerde
J. Antonsen	C. Ljuslin
H. Arandel	L. Lopez
G. Bain	D. Lord
R. Benetta	A. Luterotti
A. Berglund	R. Mc Laren
U. Berthon	D. Marland
J. Bettels	F. Marzano
R. Böck	H. Masuch
G. Bovard	J. Meyer
F. Bruyant	D. Myers
R. Budde	P. Nappey
D. Cafagno	J. Oropesa
B. Carlson	E. Pagiola
N. Carney	F. Peron
C. Caso	R. Poncet
G. Chanel	J-P. Porte
M. Couturier	E. Quercigh
R. Currat	E. Rosso
S. Dean	G. Regad
H. Drevermann	J. Schotanus
J-P. Dupraz	H. Schroter
L. Ferrand	A. Silverman
K. Geissler	L. Sohet
P. Gelissen	B. Stumpe
J-C. Gouache	B. Tallini
R. Hänni	J. Trembley
D. Harmsen	G. Trouiller
H. Hayes	A. Van Praag
D. Jacobs	C. Vollerin
W. Jank	D. Williams
E. Jansen	D. Wiskott
G. Kellner	J-C. Wolles
W. Krischer	M. Yerly
J-C. Legrand	

Special credit must also be given to our operators and their supervisors without whose interest and enthusiasm the task of starting operations on ERASME, would have been much more difficult.

REFERENCES

1. D. Lord and E. Quercigh ; "The ERASME Project Summary";  
CERN DD/DH/70-20, D.Ph.II/INST. 70/7.
2. Proceedings of the Second International Colloquium on PEPR,  
Cambridge, MIT-2098-660, May 1970.
3. H. Anders, J. Antonsen, V. Shkunderkov, B. Stumpe and D. Wiskott;  
"Dynamic Astigmatism and Focus correction of the Cathode Ray Tube  
of ERASME". Oxford Conference on Computer Scanning, April 1974.
4. J-C. Wolles : "Convertisseur Digital Analogique de haute performance",  
p. 337 Comptes rendus des journées d'électronique sur le thème  
Conversion A/D et D/A, EPFL, Lausanne, October 1973.
5. H. Anders and L. Sohet : "Track detection in ERASME for the film  
from the new generation of Bubble Chamber". CERN DD-74-1, D.Ph.II/  
INST. 74-1, Jan. 1974.
6. R.M. Brown and R.W. Downing : "The University of Illinois DOLLY System".  
"Proceeding of Internal Conference on Advanced Data Processing for  
Bubble and Spark Chambers", Argonne National Laboratory, October 1968  
(ANL-7515).
7. J. Bettels et al., "A high performance PDP-10 to PDP-11 Link". Procee-  
dings of the Eighth Decus-Europe Seminar, Strasbourg, Sept. 1972.
8. "HYDRA Systems Manual", TC Division, CERN.



TABLE 1

Specifications for Components of the ERASME System

Precision Cathode Ray Tube

Ferranti Type 18/75 AFJ	
Gun type	: Tetrode, double cross over
Phosphor	: A-type, equivalent to P24 (JEDEC Standard) Max. intensity at 500 nm
Radiant power	: $\sim 6\mu\text{W/steradians}$ at 4m/sec
Screen size	: 7"
Useful diameter	: 160mm
Overall length	: 750 mm

Deflection Coil for Precision CRT

Inductance	: 60 $\mu\text{H}$
Resistance	: 0.4 $\Omega$
Current	: 4.5 A for $21^\circ$ deflection at 25 KV, push pull
Residual magnetism	: 0.005%
Recovery time	: 20 $\mu\text{sec}$ to 0.1% (10 msec to 1 least count)
Manufacturer	: CELCO

Scan Control and Digitizing Logic

Digitizing Least Count	: 1.4 $\mu\text{m}$ for BEBC pictures $\sim 2.0\mu\text{m}$ for 2m pictures
Spot Velocity	: 5 $\mu\text{m}/\mu\text{sec}$ (typical) 20 $\mu\text{m}/\mu\text{sec}$ (maximum)

Precision Lens

Zeiss S-Planar 2.8/300

Magnification : 1:0.8 reduction  
Illuminant : Ferranti A-Phosphor, equivalent to  
P24 (JEDEC standard)  
Object field diameter : 160 mm  
Image field diameter : 128 mm  
Transparency : 85% at 500 nm  
Resolution (calculated) :  
at 40 lines / mm : 63% MTF response  
at 60 lines / mm : 40% MTF response

Photo-Multipliers

EMI Type 9656A, selected for highest quantum efficiency at 520 nm  
(sensitivity  $\sim 120 \mu\text{A/L}$ ).

Film Transport

Film formats : 70 mm sprocketed film  
50 mm unsprocketed film  
Film advancement speed : 25 cm / sec  
Positioning accuracy :  
along film axis :  $\leq \pm 0.5$  mm  
across film axis :  $\leq \pm 0.2$  mm

The film reels can take up to 300 m film.

Film stage

5 film gates for 4 stereo views and calibration grid  
Stopping precision of stage :  $< \pm 1$  mm  
Digitizing least count perpendicular  
to film axis (linear encoder) : 12.7  $\mu\text{m}$

Average time to change views	: ~ 1 sec
Maximum distance of movement	: 800 mm
Film gate	: upper glass plate fixed, lower glass plate mobile
Opening between glass plates	: 5 mm
Maximum viewing field	: 106 mm diameter

Objective Stage

Maximum speed in X and Y direction	: 75 mm/sec
Acceleration	: 1m/sec <sup>2</sup>
Digitizing least count in X and Y (rotary encoder)	: 6.35 $\mu$ m
Maximum distance of movement	: 120 mm in X-direction : 125 mm in Y-direction
Predigitizing accuracy on film	: $\pm$ 40 $\mu$ m
Predigitizing accuracy on the projection table (with 17 x magnification)	: $\pm$ 0.7 mm

FIGURE CAPTIONS

- Fig. 1        General lay-out of the ERASME system.
- Fig. 2        Block diagram of a scanning and measuring unit.
- Fig. 3        Schematic lay-out of a scanning and measuring unit.
- Fig. 4        Photo of ERASME.
- Fig. 5        Precision CRT and track detection unit.
- Fig. 6        Block diagram of video processing and track detection.
- Fig. 7        Digitizing process timing and scan patterns.
- Fig. 8        Stage Control.
- Fig. 9        ERASME interface address mapping.
- Fig. 10      The complete sequence for processing an event by ERASME.
- Fig. 11 a)    Track initialisation.
- b)    Final display to the operator.
- Fig. 12      ERASME software structure.
- Fig. 13      Typical settling time behaviour as a function of the distance over which the spot is moved.
- Fig. 14      Calibration residuals :
- a)    enlarged distances between the measured cross position and the position calculated from the fit.
- b)    histogram of these distances.
- Fig. 15      Calibration for the four different film gates.
- a)    using the transformation coefficients of gate 5.
- b)    using the coefficients calculated for the gate itself.
- Fig. 16      Stability of the calibration. The crosses give the average and maximum residuals obtained using the coefficients from the initial calibration while the dots give the same information after recalibration.

Fig. 17      Invariant mass squared distribution :

- for 252  $K_0$  particles

a) measured by ERASME

b) measured by the CERN HPD II

- for 119  $\Lambda$  particles

c) measured by ERASME

d) measured by the CERN HPD II.

Fig. 18      Average residuals after geometric reconstruction for fast beam  
and outgoing  $K^-$  tracks ( $p > 10$  GeV/c) from 298 2- and 4- pronged  
events which had a 4- constraint fit to the reactions

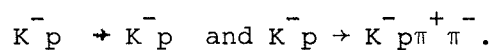
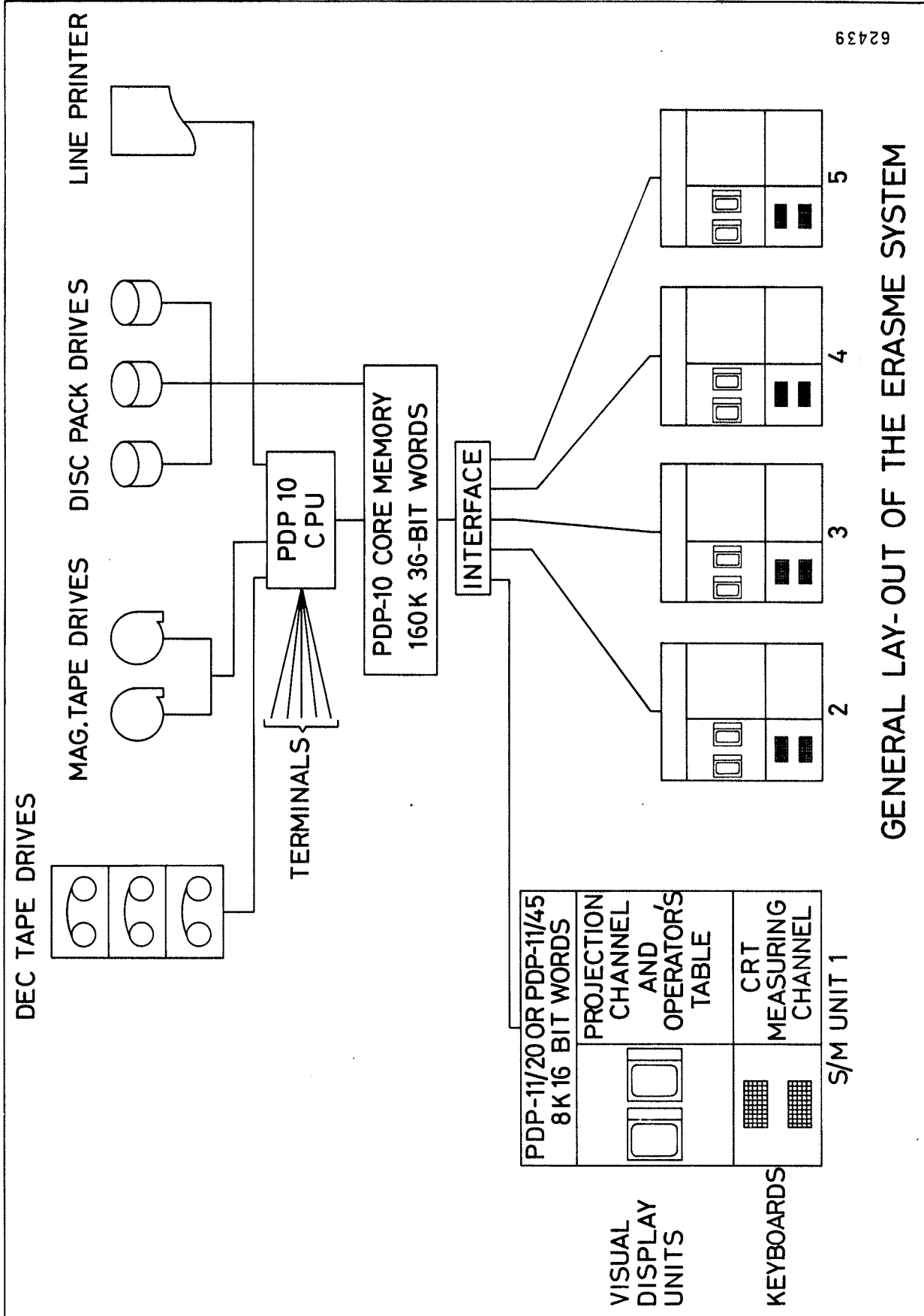


Fig. 19      Typical BEBC picture from the 9 GeV/c  $K^-$  run of November 1973.

Fig. 20      Distribution of average residuals from 43 non interacting beam  
tracks in BEBC - measured on S/M-2.

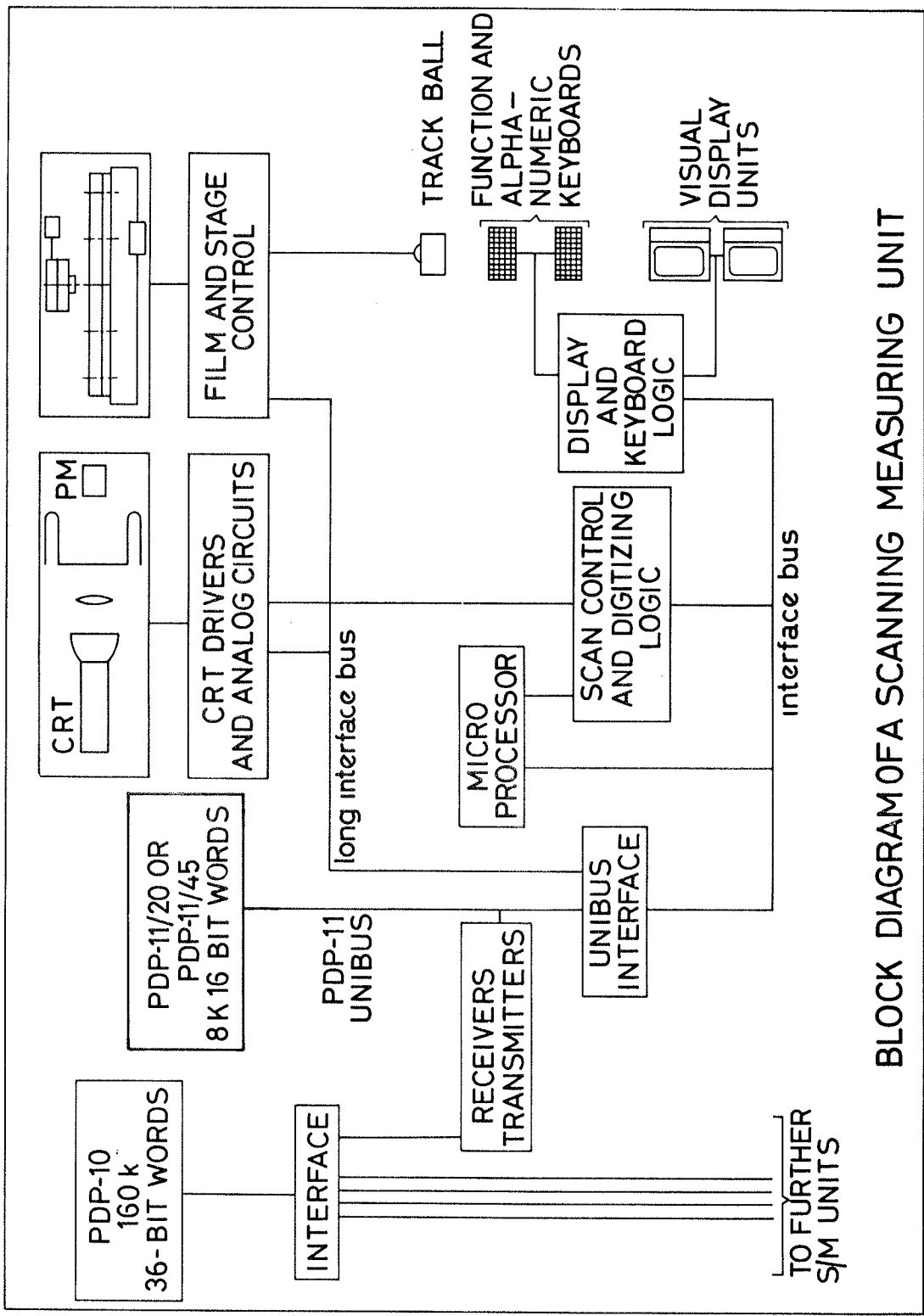
Fig. 21      ERASME Special On-line Processor (ESOP).



62439

GENERAL LAY-OUT OF THE ERASME SYSTEM

Fig. 1



BLOCK DIAGRAM OF A SCANNING MEASURING UNIT

Fig. 2

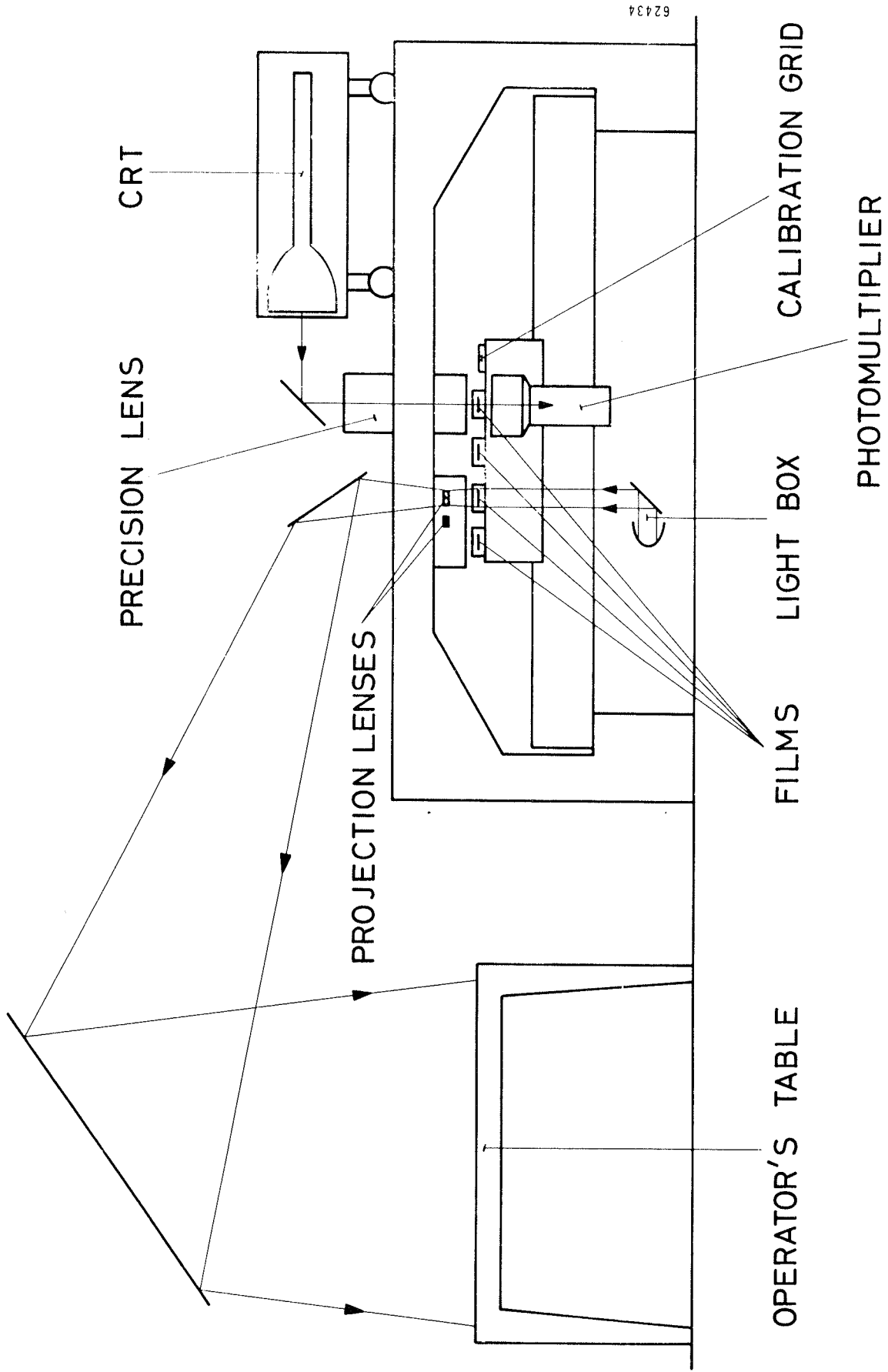


Fig. 3



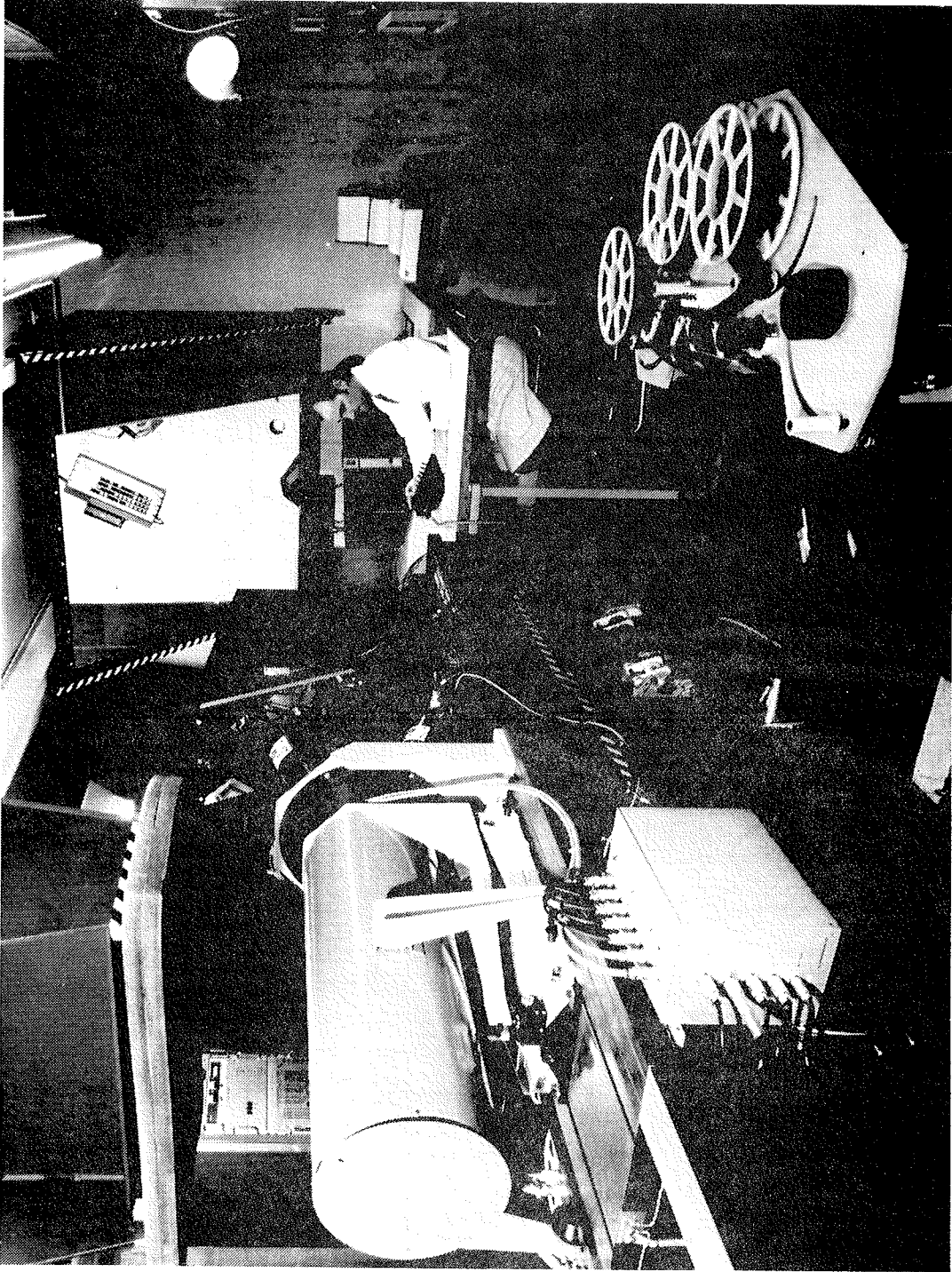
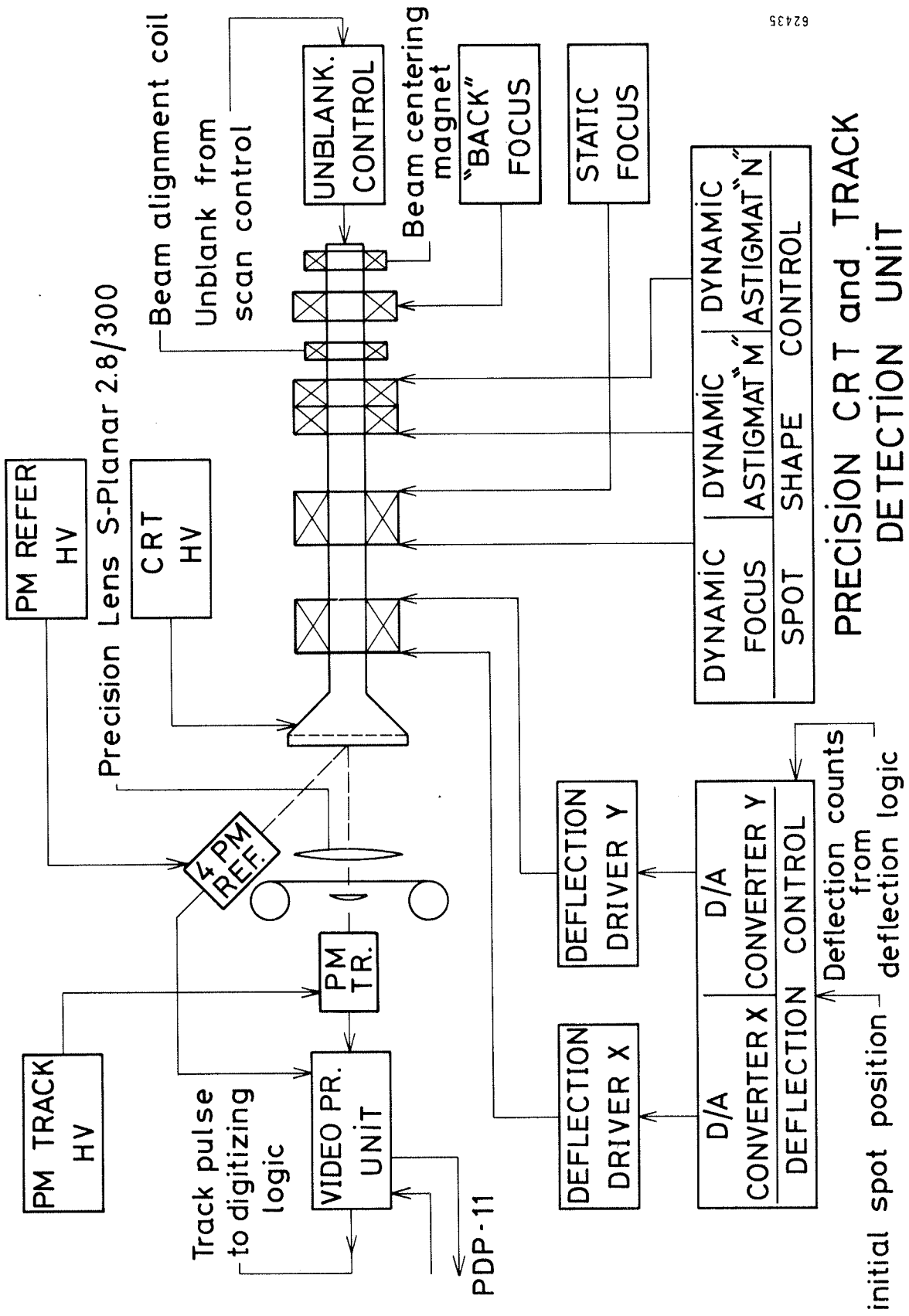
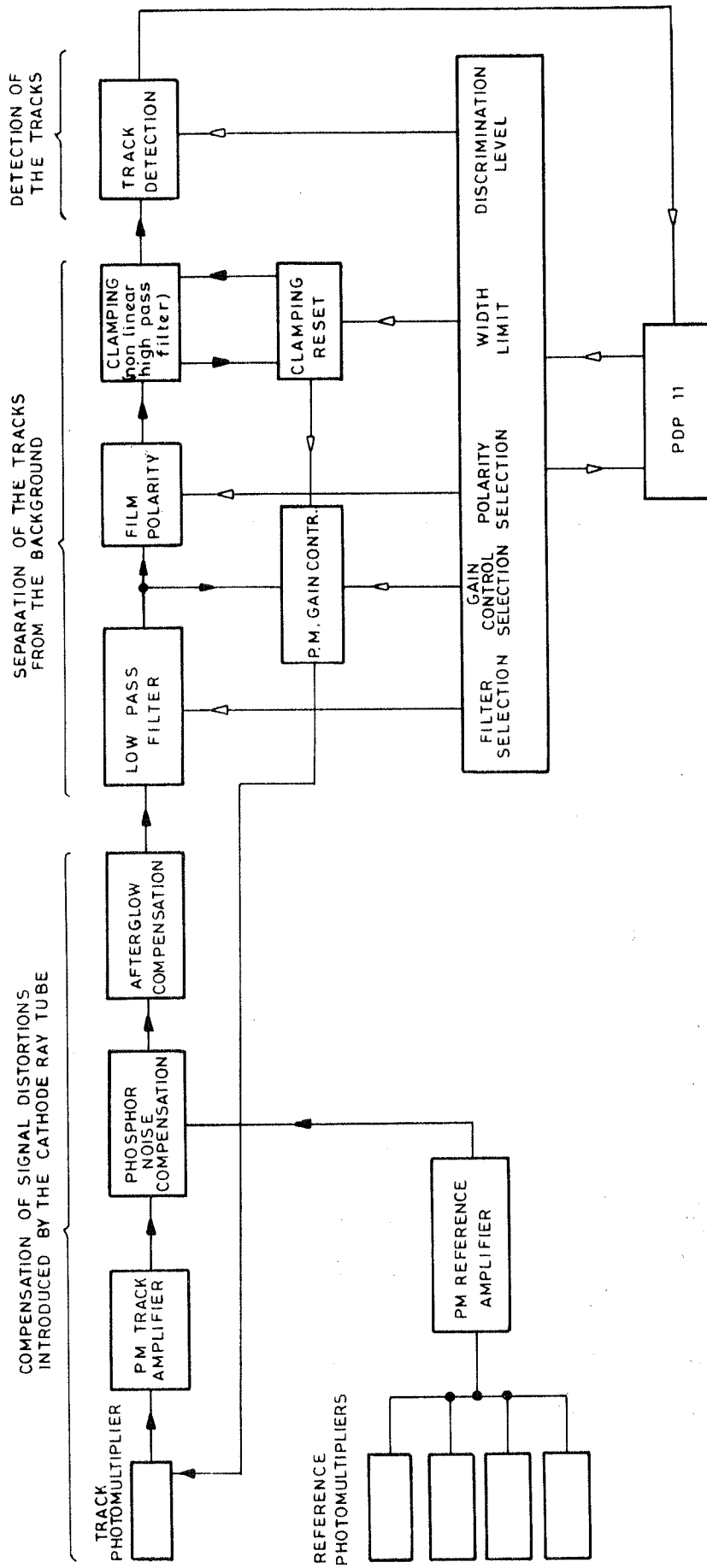


Fig. 4



62435

Fig. 5



Block diagram video processing and track detection

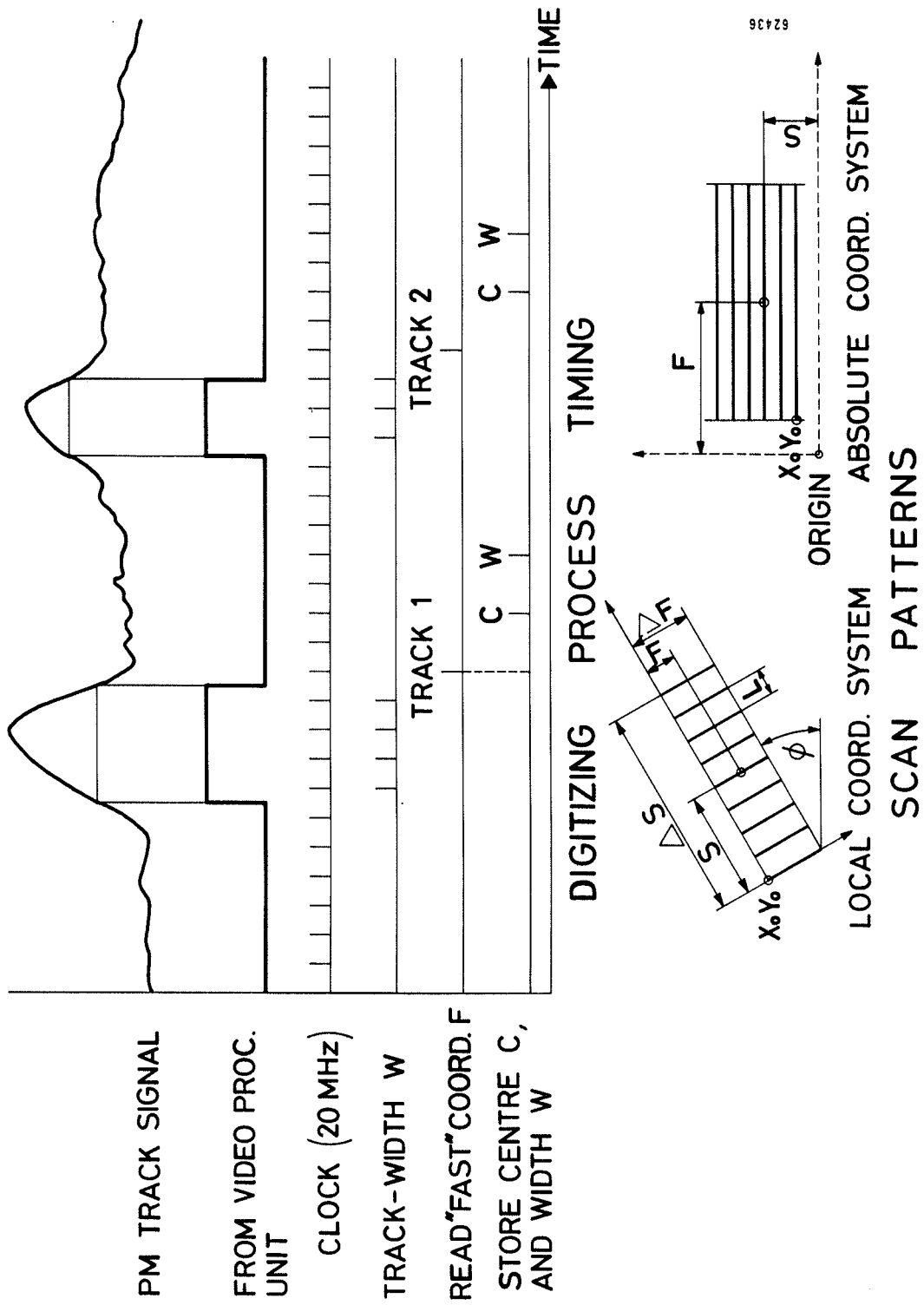
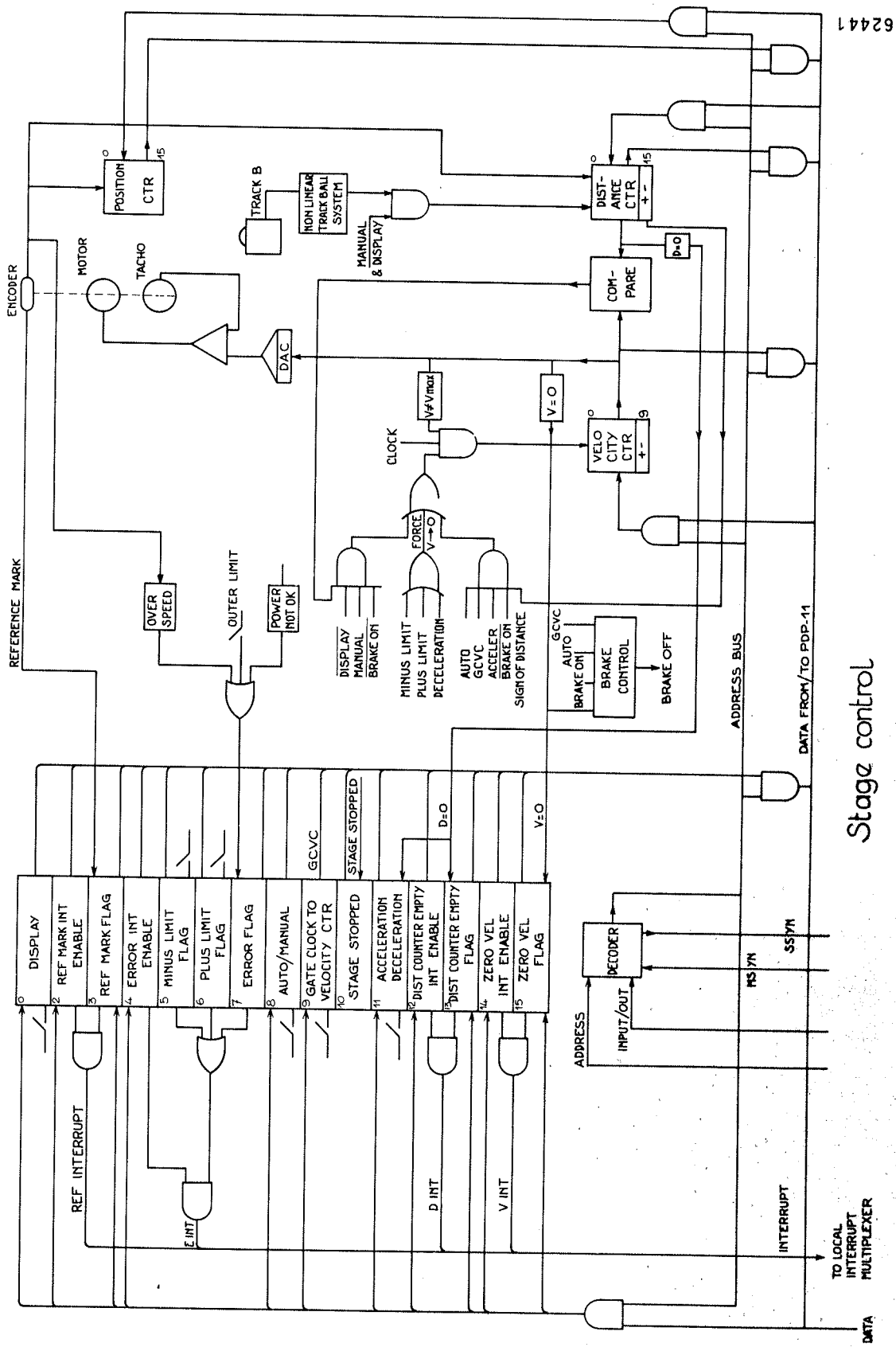


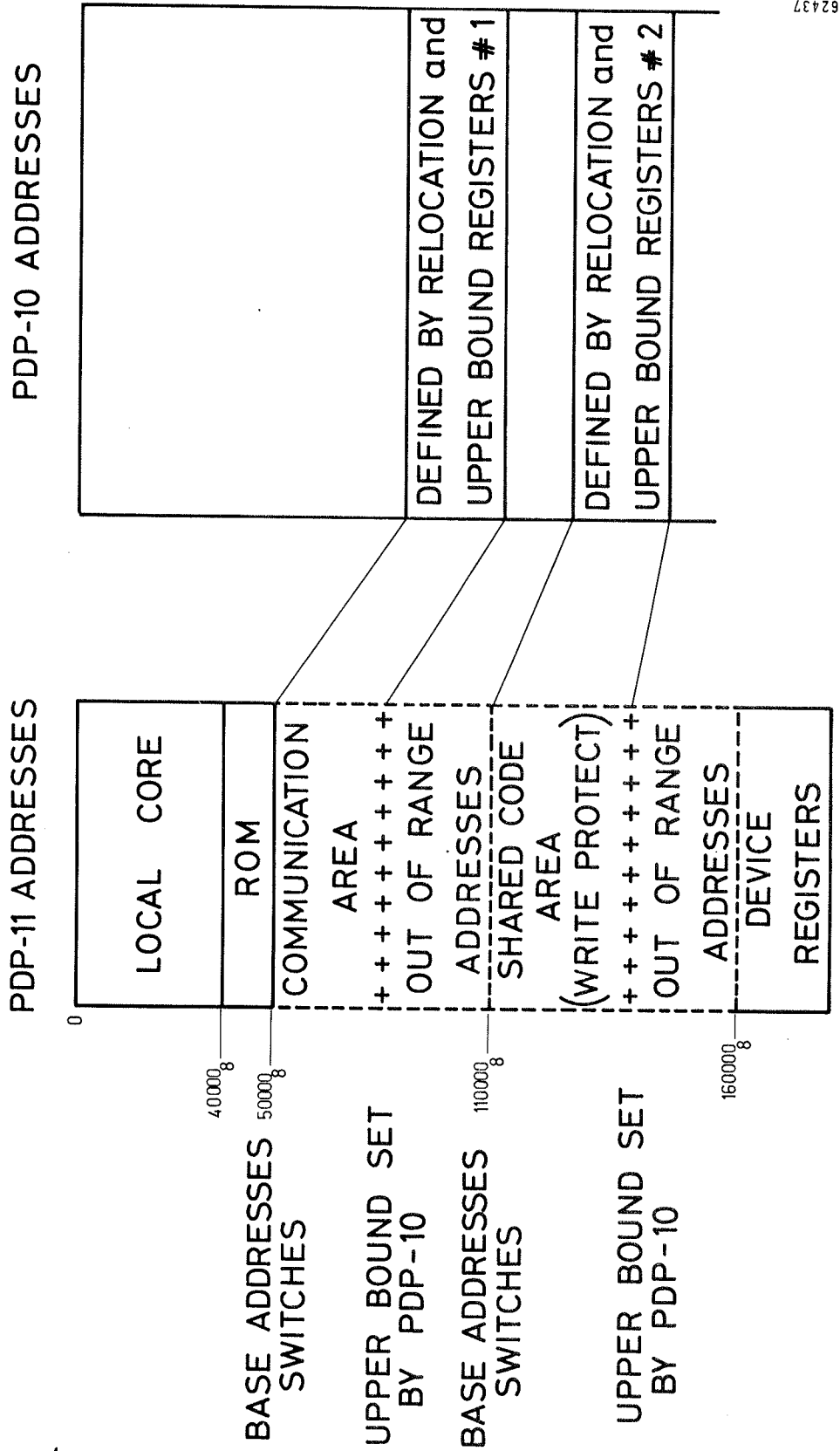
Fig. 7



Stage control

Fig. 8

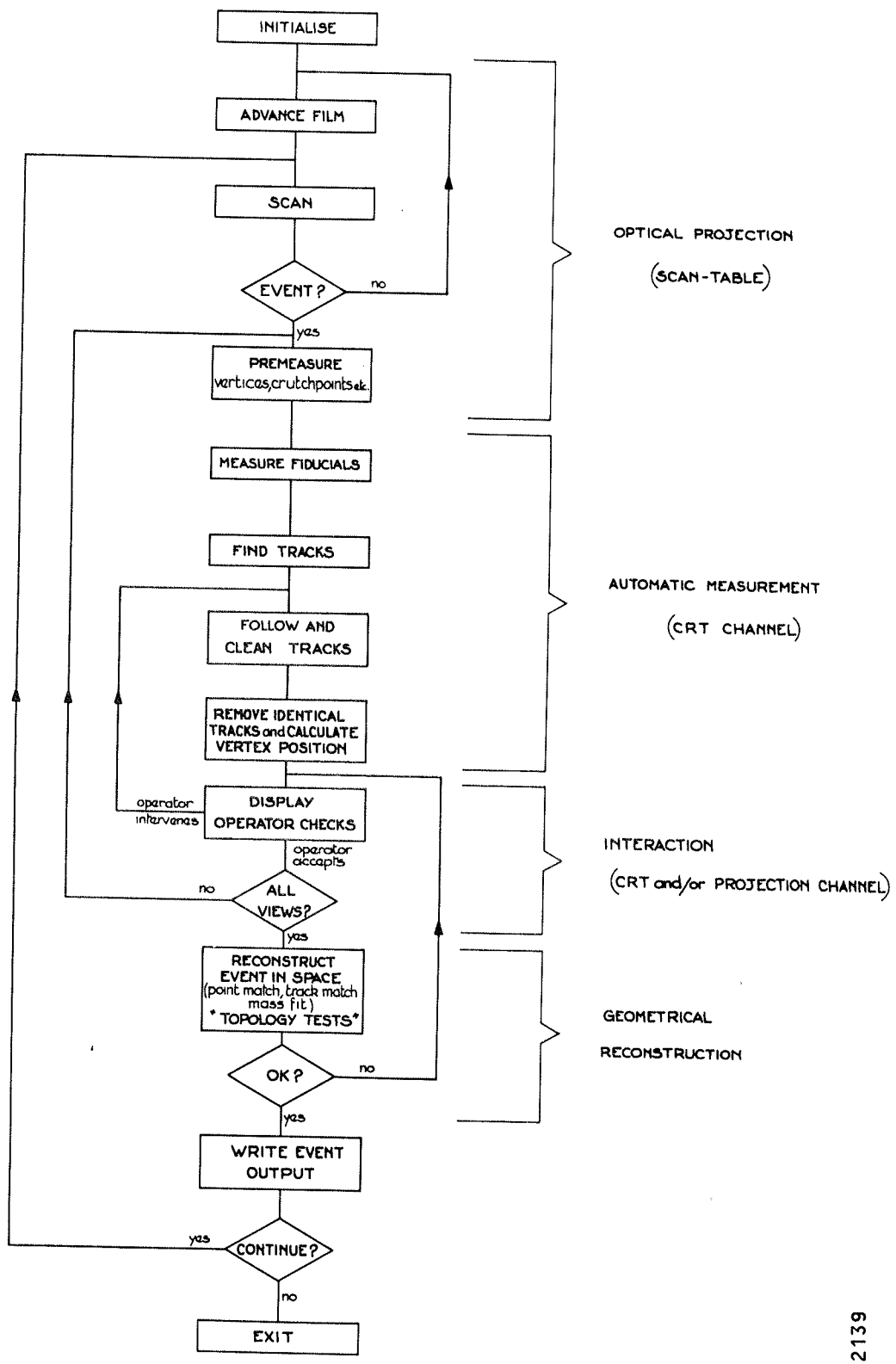
62441



62437

### ERASME INTERFACE ADDRESS MAPPING

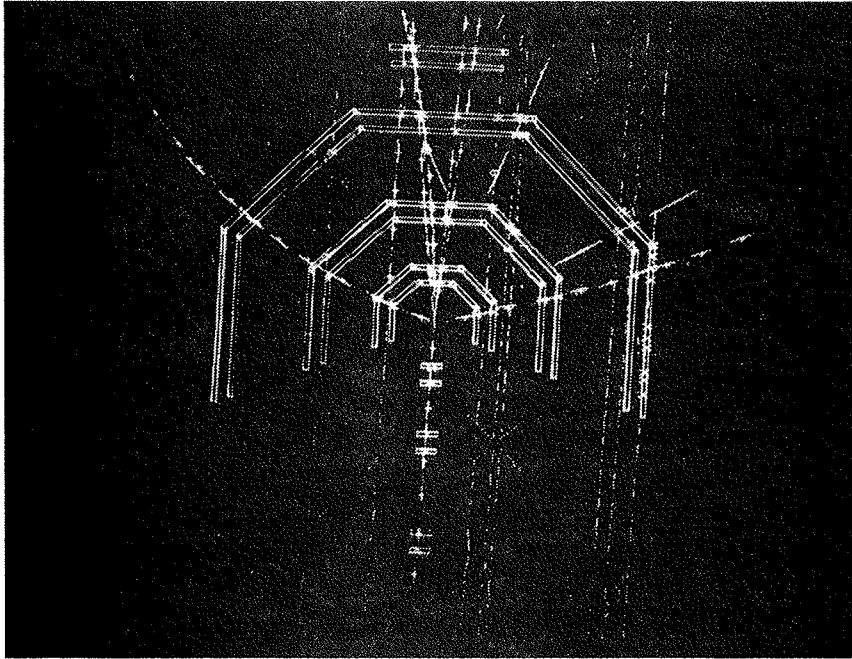
Fig. 9



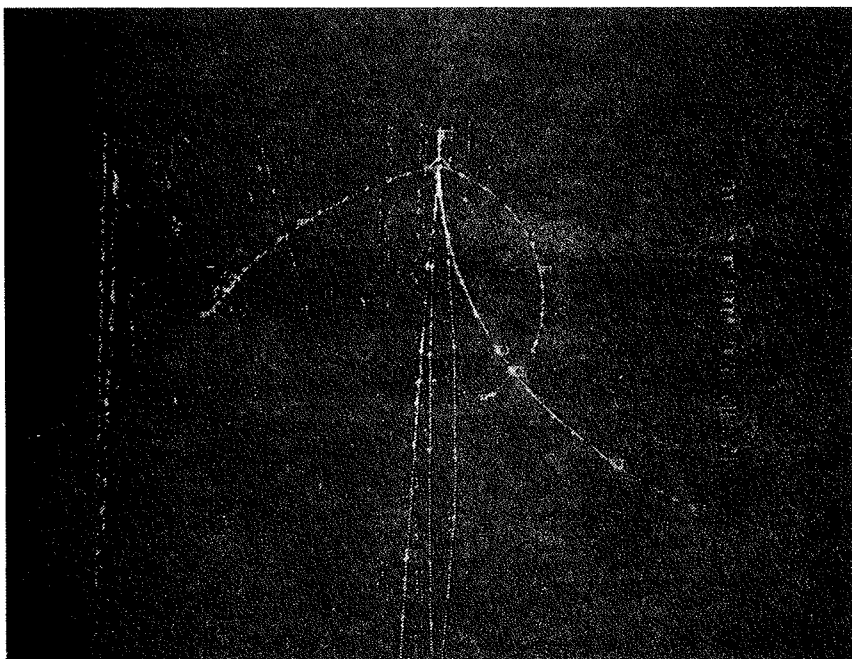
62139

The complete sequence for processing an event by ERASME

Fig. 10



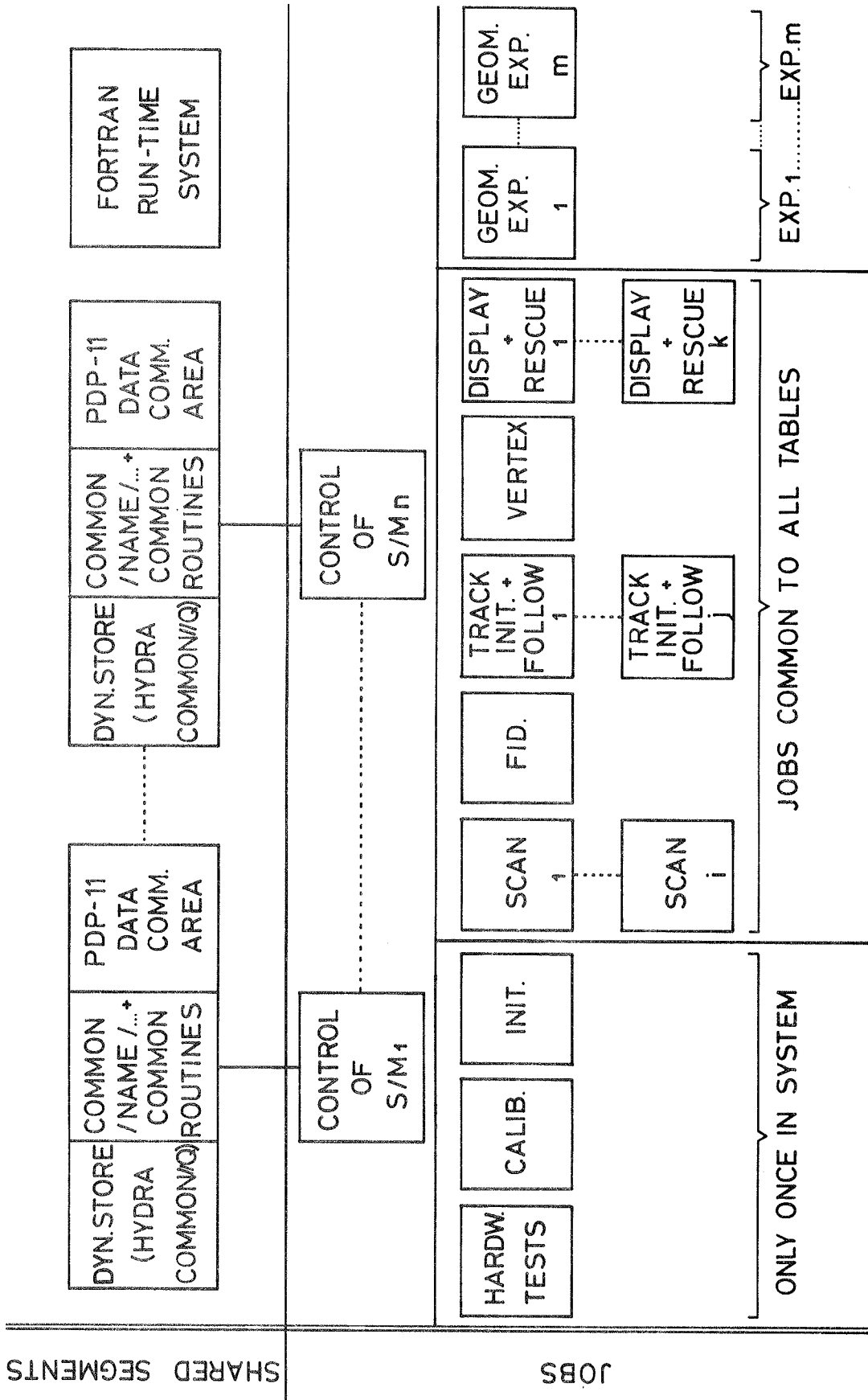
a)



b)

Fig. 11





ERASME software structure

Fig. 12

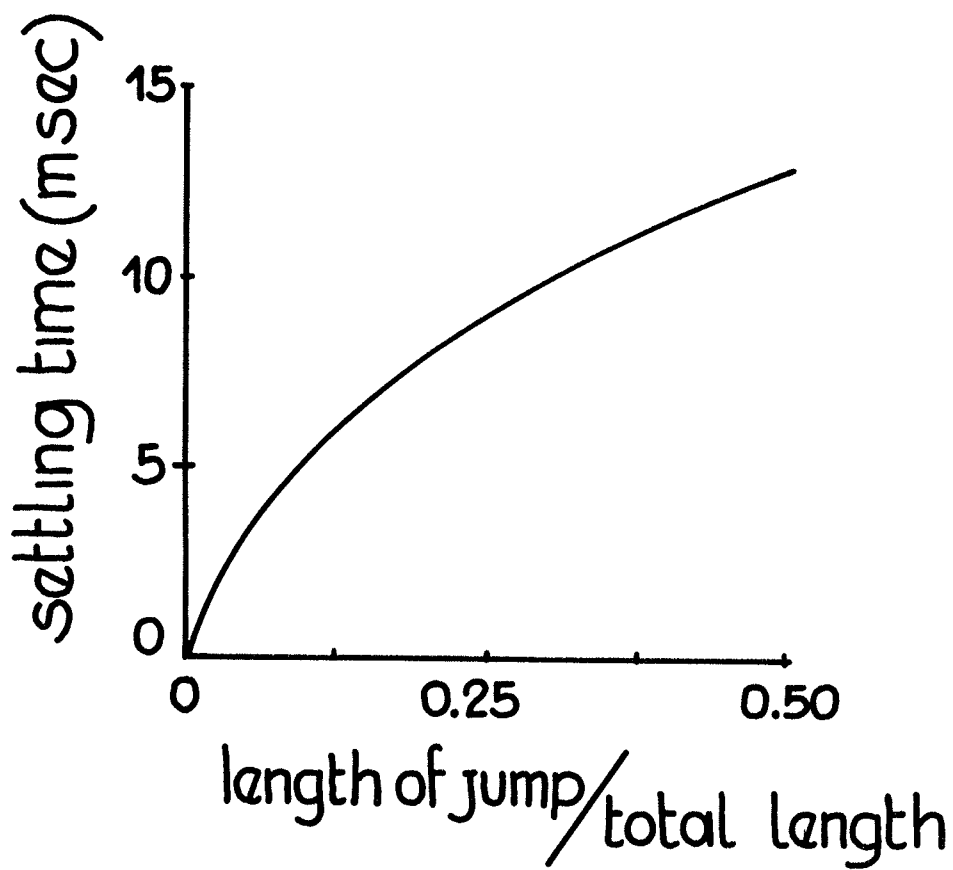


Fig. 13

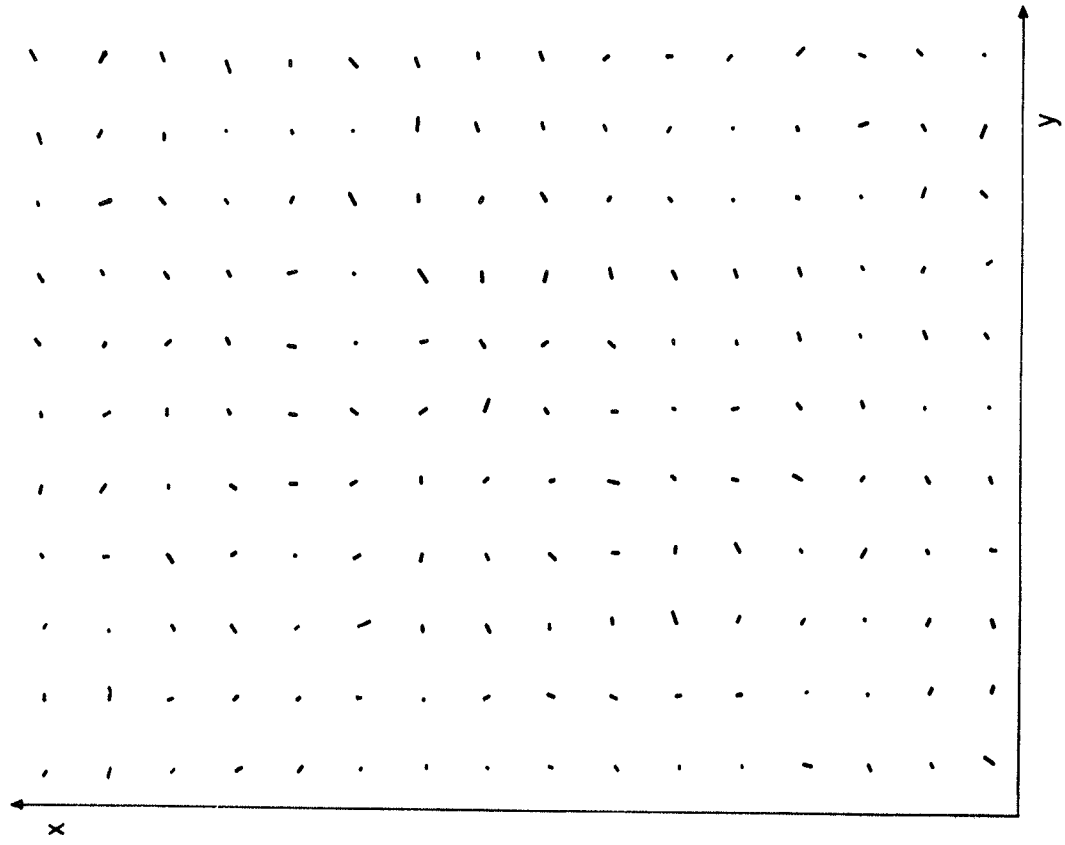


Fig. 14 a)

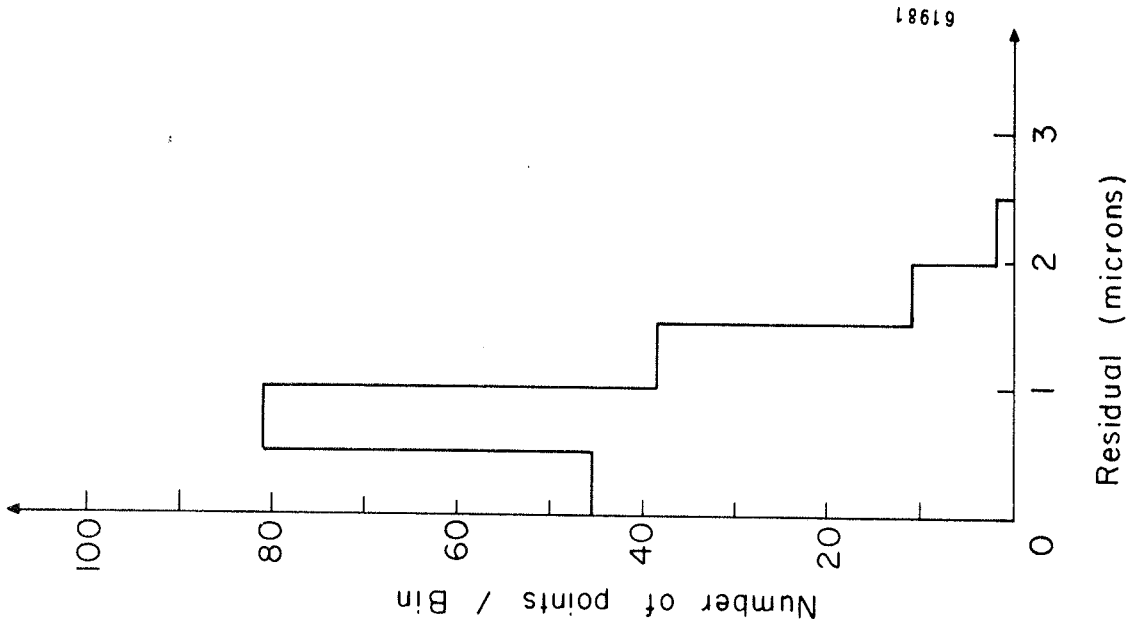


Fig. 14 b)

61981

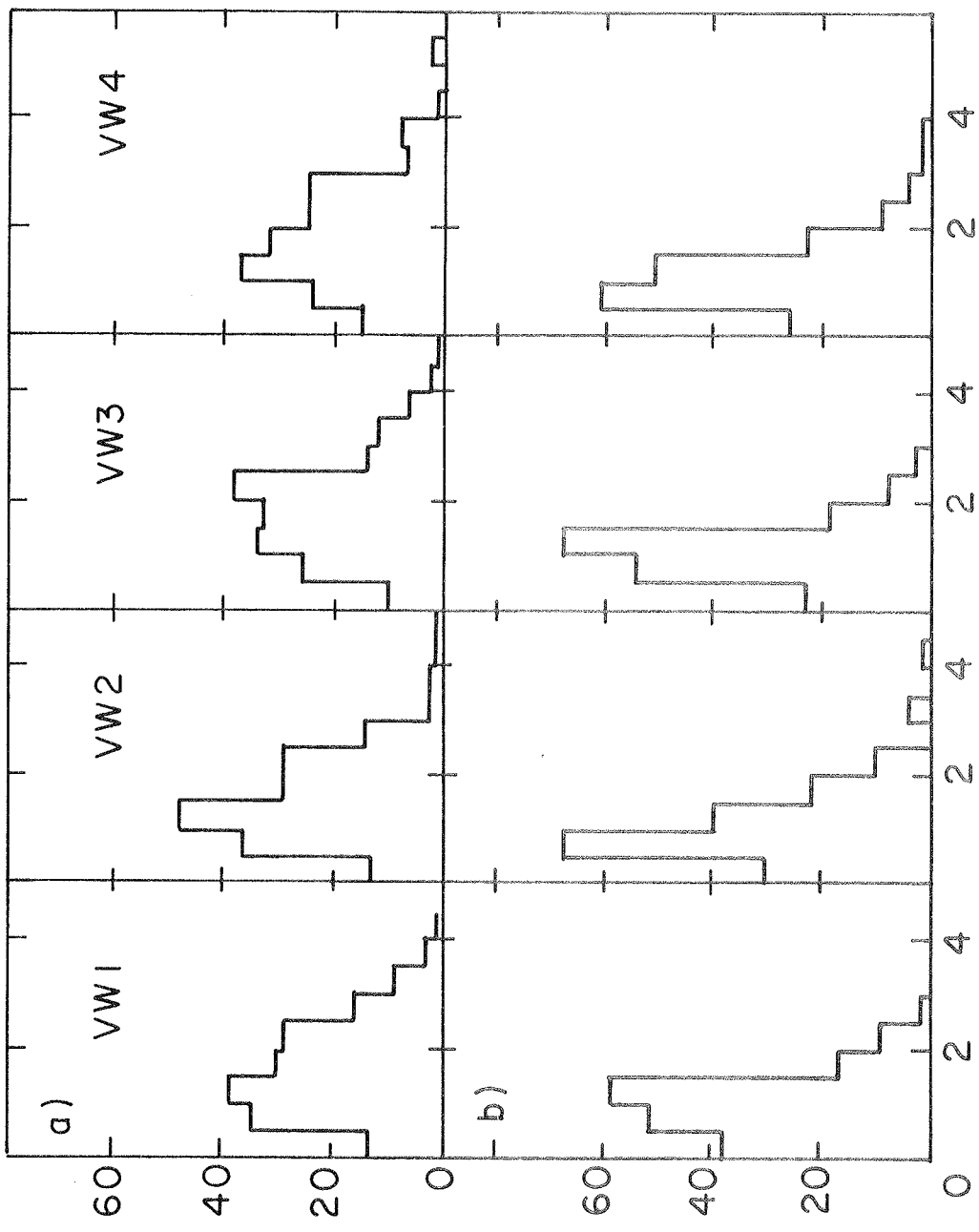
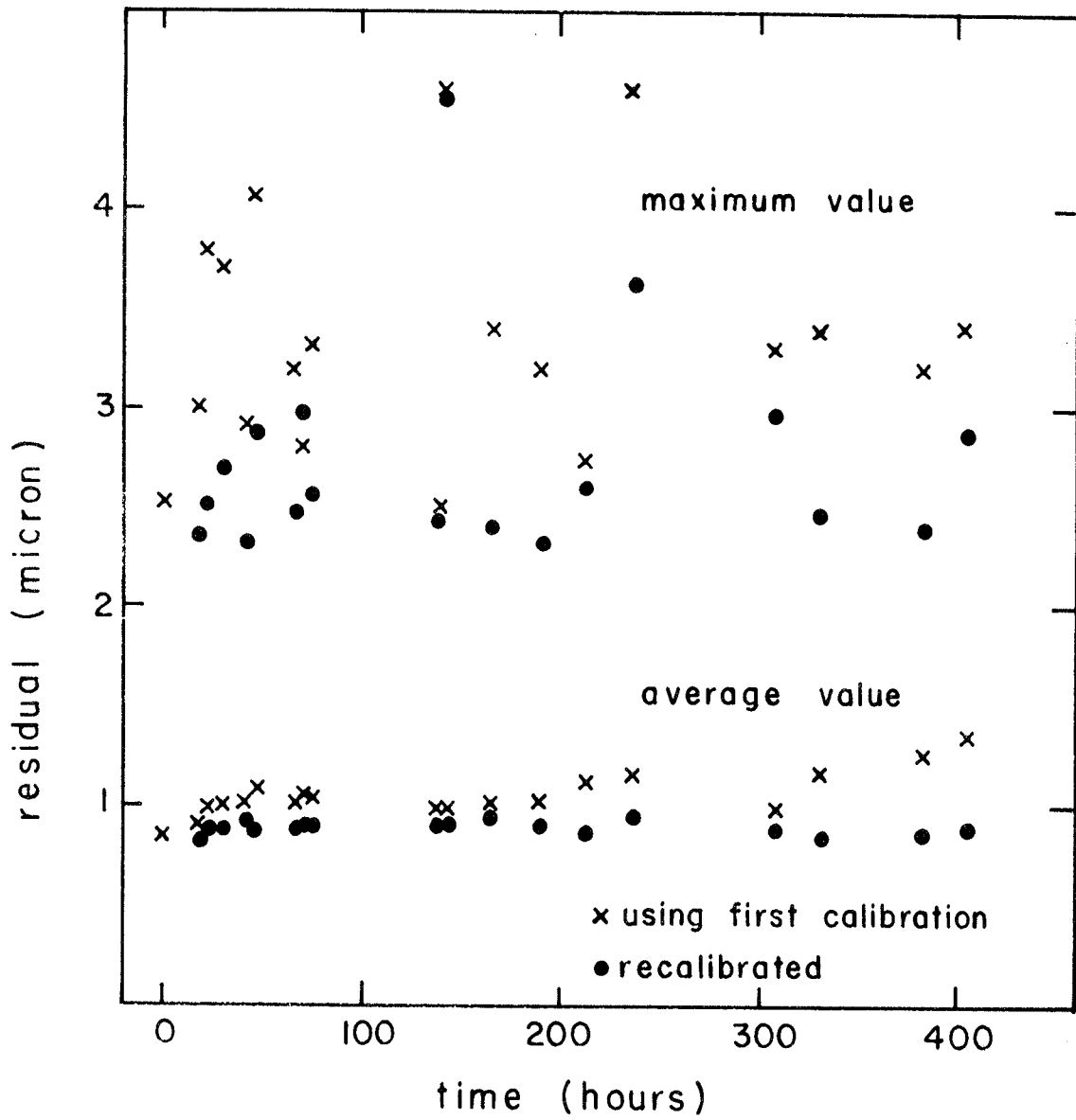


Fig. 15 a)

Fig. 15 b)



61980

Fig. 16

Fig. 17 a)

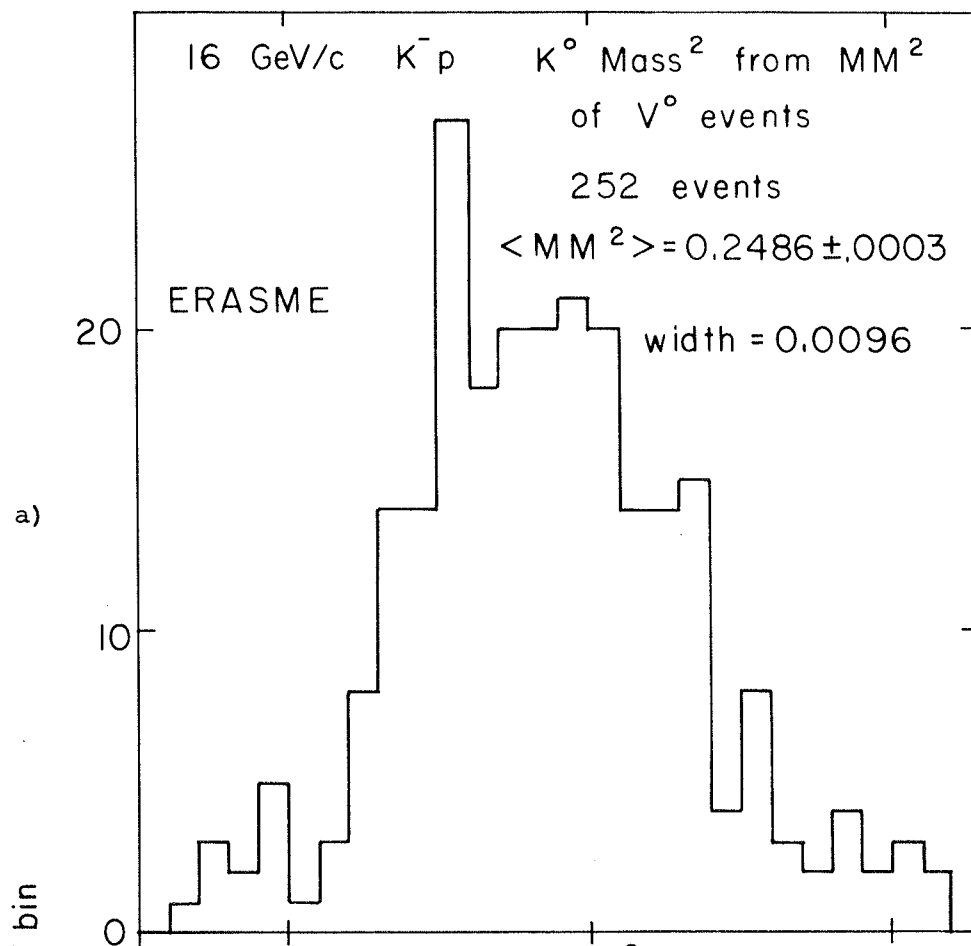
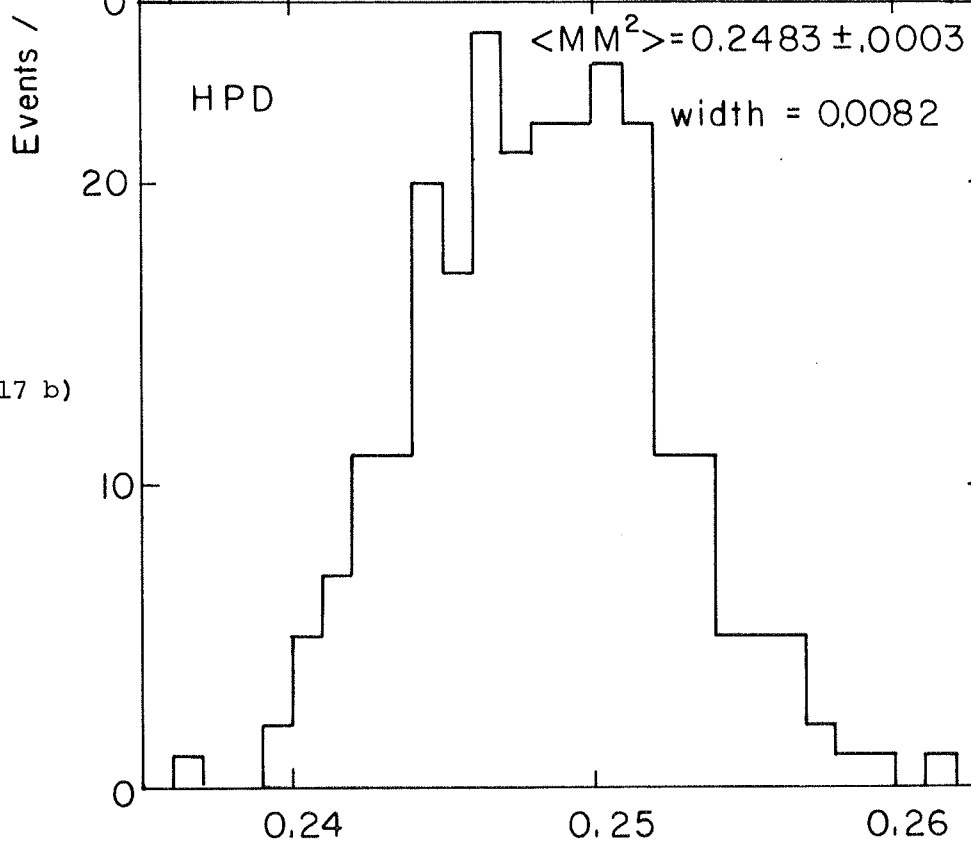


Fig. 17 b)



$M^2$  (GeV<sup>2</sup>)

Fig. 17 c)

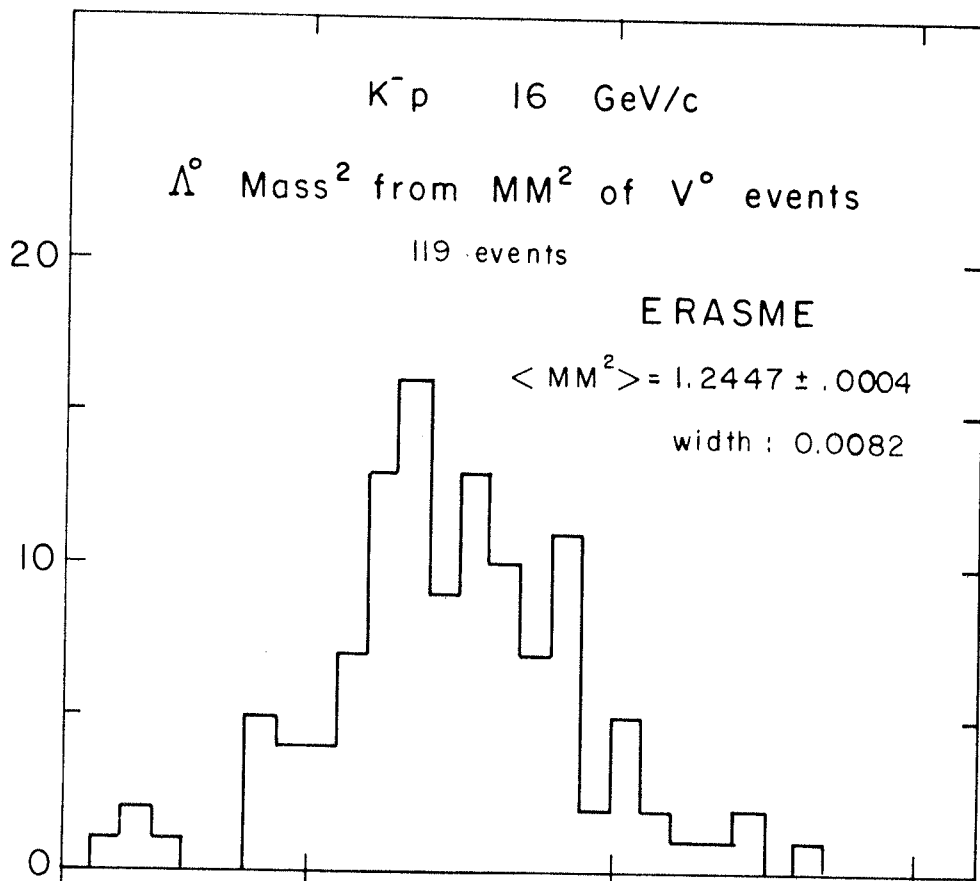
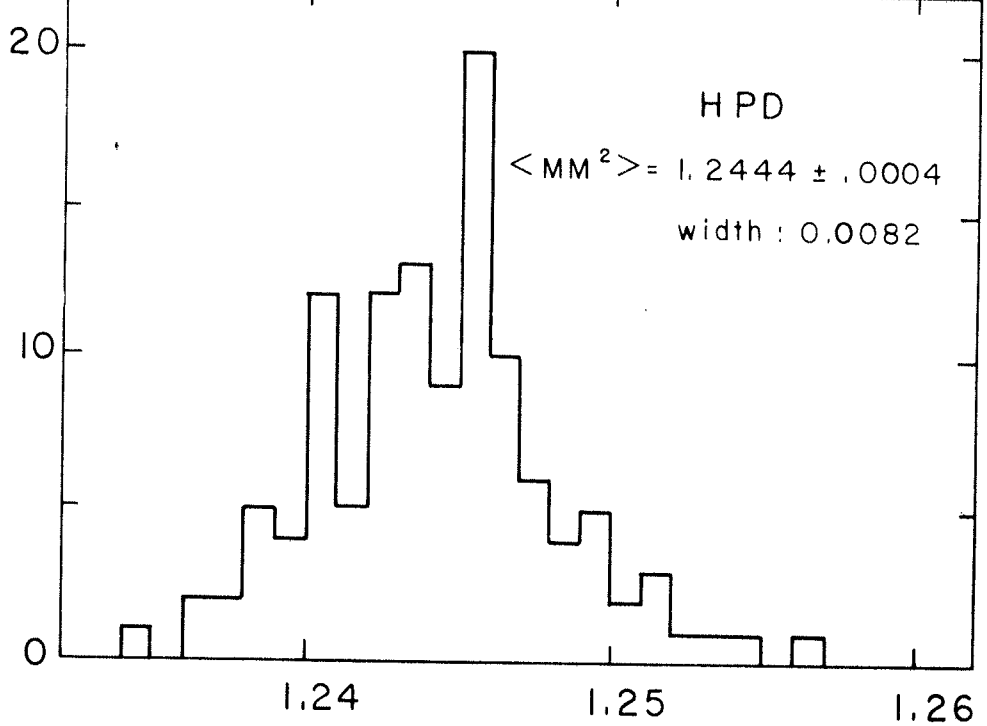


Fig. 17 d)



$M^2 (\text{GeV})^2$

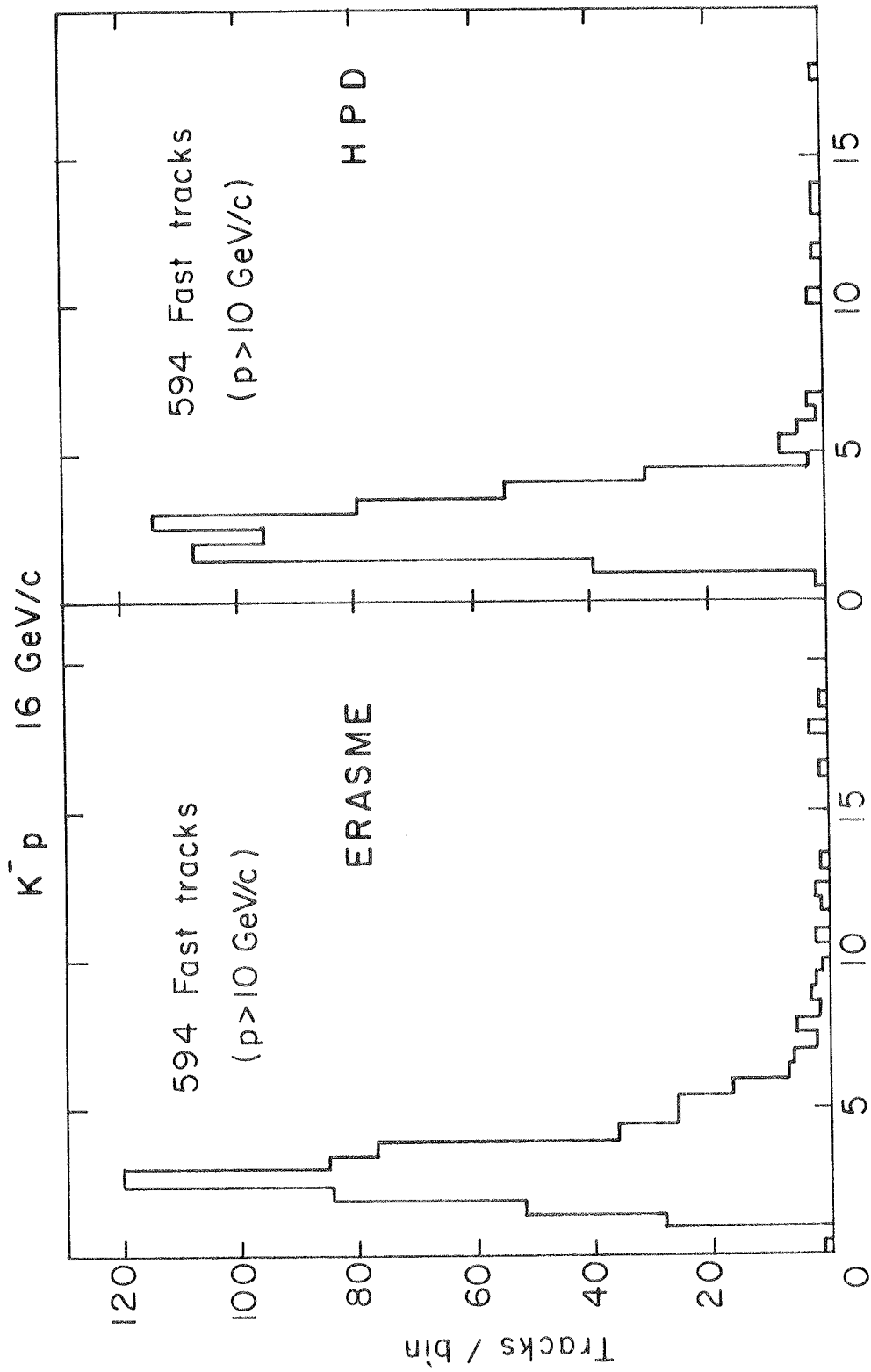


Fig. 18



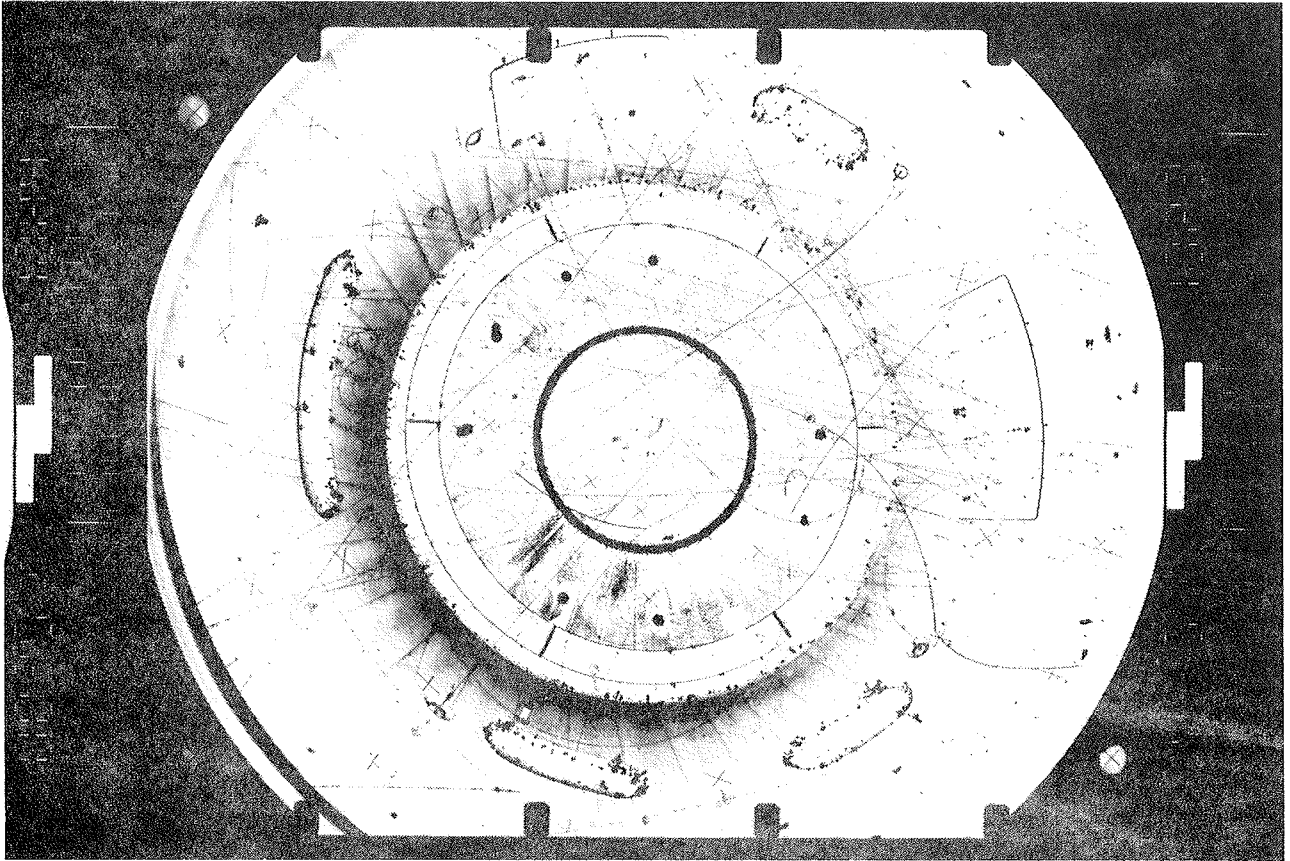


Fig. 19

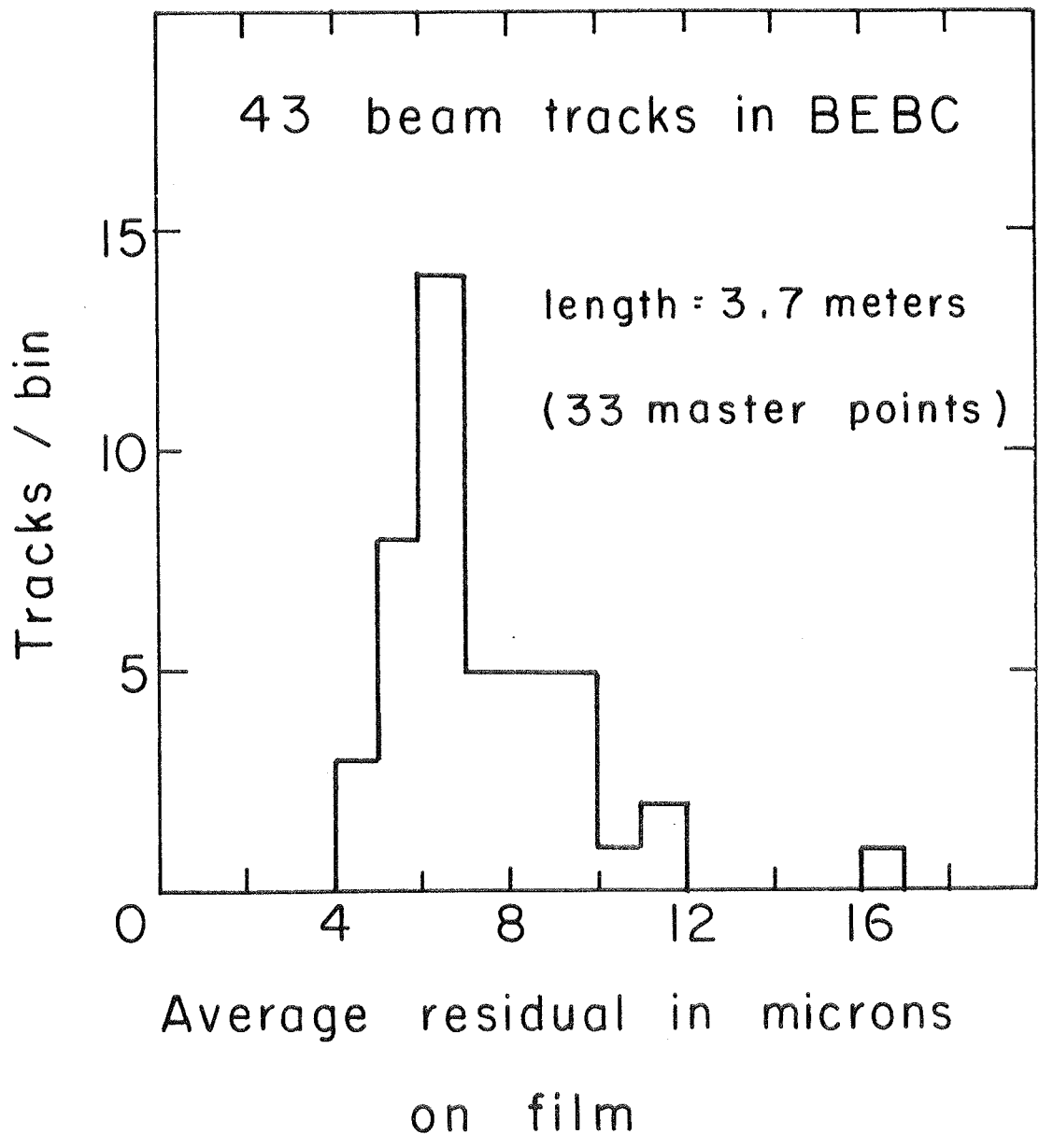
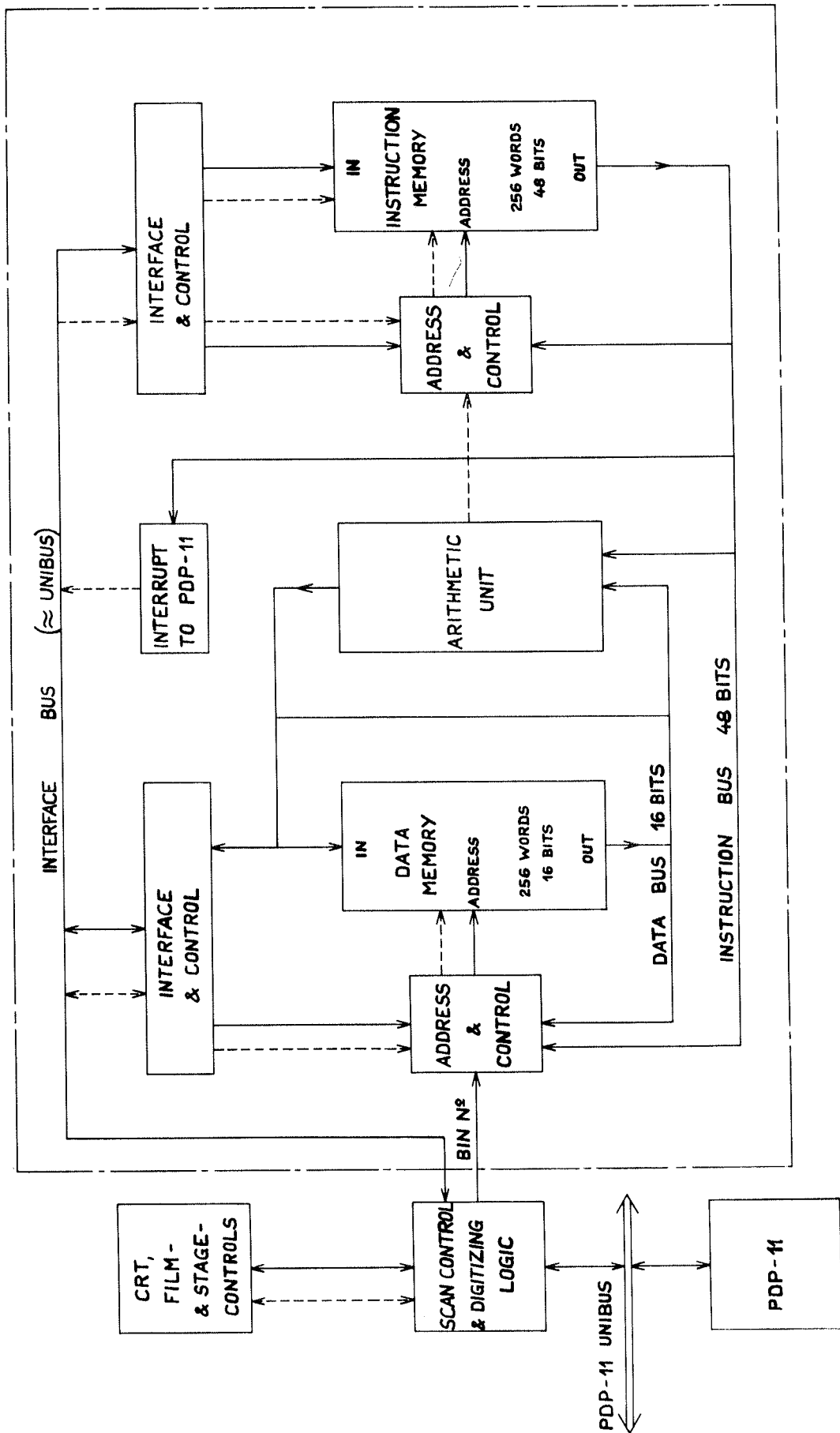


Fig. 20



----- CONTROL SIGNALS

# ERASME Special On-line Processor (ESOP)

Fig. 21