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CONSTRUCTION AND PERFORMANCE OF THE SCANNING AND MEASURING MACHINE HOLMES USED FOR BUBBLE CHAMBER HOLOGRAMS

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ABSTRACT

The construction and performance of the scanning and measuring machine HOLMES are described. It has been used to analyse in-line holograms taken with the small bubble chamber HOBC. A total of 8000 holograms has up to now been analysed on HOLMES.

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1. INTRODUCTION

In particle physics the bubble chamber has been an important device to study particle interactions. The size of the bubble chamber has very much been dictated by the lifetime of the produced particles that one wanted to observe. The decay of the particle usually determines its identity. For the charm particles, with their short lifetimes ($\sim 10^{-13}$ s), very high spatial resolution is necessary for their detection. As their decay length is short (about one or a few millimetres) the bubble chamber can be small without affecting the detection efficiency.

A recently developed high resolution detector is the holographic bubble chamber. The main advantage of holography is the possibility of obtaining high resolution and a large depth of field simultaneously. With a conventional optical system the depth of field and the resolution are related, and high resolution can only be obtained at the expense of the depth of field. The feasibility of holography of bubble chamber tracks were performed using a small heavy liquid bubble chamber [1].

Here we report on the CERN scanning and measuring machine HOLMES used to analyse holograms from the first holographic bubble chamber experiment NA25 [2] performed at the CERN SPS. The aim of the experiment was to determine the charm cross section with 200 and 360 GeV/c incident particles.

In sec. 2 we describe the production of the holograms and in sect. 3 the design and construction of HOLMES. The performance of HOLMES is described in sect. 4 and the summary is presented in sect. 5.

2. PRODUCING THE HOLOGRAMS

The holographic set-up is shown in fig. 1. The two stage excimer-dye laser produces 10 ns pulses with a maximum frequency of 30 Hz. A wavelength of 514 nm was selected in order to match the green argon line for the replay system.

The bubble chamber HOBC is a small, heavy liquid, rapid cycling bubble chamber designed for the use of in-line holography [3, 4]. The chamber is filled with freon C_3F_8 and the visible volume is $5 \times 6 \times 11$ cm^3. The produced bubbles had a diameter of 12 µm.

The quality of the hologram showed to degrade very rapidly with increasing distance between the bubble chamber and the film. For this reason a lens system was introduced that produced a three-dimensional image of the bubble chamber tracks very close to the film. This three-dimensional image of the tracks, rather than the tracks themselves, was holographed. With this arrangement the distance between the film and the middle of the bubble chamber appears to be 45 mm.

The principle of in-line holography is illustrated in fig. 2 (the transfer lens used at the recording is not shown). A hologram is produced by recording on film the interference pattern between the scattered light and the coherent plane wave illumination. For bubbles of 12 µm diameter and a laser wavelength of 514 nm, 80% of the scattered light is contained in a cone with angle 33 mrad. For larger objects this angle will be smaller. On film this cone covers a disc with a radius between 0.5 and 2.5 mm depending on the position of the bubble. The scattered light beyond this disc is practically lost in the noise of the film.

3. DESIGN AND CONSTRUCITON OF HOLMES

HOLMES is intended for three-dimensional evaluation of in-line holograms(*) produced with plane wave illumination. It covers a volume somewhat larger than the volume of the bubble chamber HOBC. For the reconstruction of the original bubble image the film is illuminated with coherent light of the same wavelength as was used for the production of the hologram (514 nm). A bright real image of the bubble against a dark background is formed as well as a virtual image of the bubble on the other side of the film.

The reconstructed real image is projected by a transfer lens onto a set of three television cameras and shown on television monitors. An important feature is the display of the image with different magnifications, not only such that some monitors show enlarged parts of the image, but also such that the magnification can be different in x and y for the same camera. The x, y plane is parallel to the film plane, with x in the direction of the incident beam particle. The z coordinate describes the depth in the bubble chamber. For the detection of charm decays that give rise to secondary particles in a very narrow cone, this feature of using different magnifications is of great importance.

(*) It is easy to replace the hologram by conventional film as long as the bubble images on the film are of about the same size as in the holographic case.

3.1 Optics

The air cooled argon laser has an effect of 15 mW for the green line (514 nm). The laser beam is expanded to a diameter of 15 mm and via three mirrors the expanded beam is directed perpendicularly on the film. The hologram is clamped between glass plates which move on the x stage perpendicular to the illuminating beam (fig. 3).

The optical axis is moved in the y direction over the hologram by moving the two mirrors (M1 and M2 in fig. 3 and 4) on the y stage. The variation of the distance between the reconstructed image and the transfer lens is achieved by moving the two mirrors (M3 and M4 in fig. 3 and 4) on the z stage.

The transfer lens and the spatial filters are moved on the zoom stage. A change of the distance between the transfer lens and the cameras results in a change of the magnification, which ranges from 0.6 to 2.0. As the best compromise between a sufficiently large field of view and a sufficiently good resolution, a magnification of 1.3 was normally used for the NA25 Experiment.

All four stages are mechanically independent of each other. However, a movement of the y stage as well as a movement of the zoom stage results in a change of the focalised plane in the reconstructed image. This necessitates an automatic correction, which is computer controlled, and results in a movement of the z stage.

We use a transfer lens REPRO CLARON 305 mm f:9 to position the image plane at a convenient place further away. Behind the transfer lens the light is split by two semitransparent prism cubes into three beams directed onto the photocathodes of camera 1 and 2 and via a second lens (COMPONON S 100 mm f:5.6, magnification 6.7) onto the photocathode of camera 3.

To examine different parts of the image the transfer lens with the cameras and the hologram must be moved relative to each other along the three axis x, y, z. The coordinates of a point are measured by moving the point to a fixed screen position and by recording the stage coordinates. In this case the same optical path is always used and the measurement is independent of the quality of the transfer lens and the photocathode of the cameras.

The image quality is altered by inserting a spatial filter into the focal plane of the transfer lens. By introducing a black disc at the focal point the light which is not diffracted by the hologram (zero order) and the light passing beside the hologram is eliminated. This is illustrated in fig. 5. Newton rings produced between some of the glass surfaces (lens, vidicon etc.) vanish with the light of zero order. By increasing the radius of the disc one can furthermore eliminate big bubbles or other large structures and retain the small ones.

For practical purposes it is convenient to replace the disc, which is difficult to support, by a long strip passing through the focal point. The effective width of a thin strip can be modified by turning it. When using a strip all continuous lines (heavily ionized tracks, scratches on film etc.) perpendicular to the strip are eliminated. By increasing the width, even those lines which are not totally perpendicular are eliminated too, as can be seen from fig. 6.

All three cameras are equipped with rotary spatial filters. The filtering strip (24 mm x 6 mm x 0.4 mm) extends in the y direction. It can be moved in and out and rotated, so that the effective width varies between 0.4 and 6 mm. In this way objects bigger than 360 microns for a width of 0.4 mm down to objects bigger than 24 microns for a width of 6 mm are filtered out.

3.2 Mechanical construction

Mechanically, HOLMES is constructed such that heavy items like film rolls, film transport system and cameras are fixed, while the stages carry only light optical elements (fig. 3). All movements are horizontal. For mechanical stability HOLMES is mounted on a thick low precision base of granite. The stages run on air cushions. The x stage is guided by a block of granite manufactured with high precision. The three other stages (y, z and zoom) move on a third granite block of high precision to assume that their respective motions are parallel. For the y, z and zoom stages high stiffness yet contactless guidance is accomplished by the combined action of air cushion support incorporating a vacuum pocket section inside the air cushion (fig. 7).

All stages are driven by ball screws. The positions of the x and y stages are read out via linear encoders with a least count of 1 micron, whereas for the z and the zoom stage rotary encoders are fixed onto the ball screws and have a least count of 5 microns.

HOLMES is equipped with a film gate of dimensions 174 mm (x) x 119 mm (y). It allows the mounting of two films of 50 mm width. Normal scanning and checking may be done successively on different films without changing film. The film transport system is built to handle two films with a maximum speed of 8 frames/s. The high speed is particularly convenient for the reinvestigation of the relatively few highly interesting interactions on a roll. The film transport is computer controlled, A photograph of HOLMES is shown in fig. 8.

3.3 The cameras

The patterns to be analysed consist of tracks formed by bubbles. As there is no magnetic field in the bubble chamber HOBC, the tracks form straight lines. Most tracks emanating from the vertex lie in a forward cone as demonstrated by fig. 9 and the image of fig. 10, which was produced by camera 2. In order to disentangle the forward tracks, an anamorphic camera (camera 2) is used, which has a horizontal magnification (y) four times bigger than the vertical one (x). A comparison of fig. 9(a) and 9(b) shows how the forward going tracks are spread out, whereas the horizontal tracks are brought together (also fig. 10). Kinks on forward going tracks and similar patterns are much more easily recognised on camera 2, whereas the sideways going tracks are better resolved by camera 1.

Camera 3 displays an image which is further enlarged by the second lens with a magnification of 6.7. The camera is modified to give an anamorphic ratio of 1:2. It is used for precise focusing. Experience has shown that the non-filtered image is generally preferred by the operator.

All three cameras (Bosch type TYK9A) are equipped with vidicons and with automatic gain control. The automatic gain control is necessary as the amount of light falling onto the photocathodes is quite different and varies considerably with the width of the spatial filter. The gain of the cameras can also be changed by the operator.

The resolution of the cameras was measured at the centre of the photocathode by means of a grid of equidistant black and white vertical lines. Table 1 gives the line width for the case when the camera output signal has a modulation depth of 50%. Table 1 also describes the dimensions of the vidicon area used.

TABLE 1

Characteristics of the cameras

	Camera 1	Camera 2	Camera 3
Anamorphic ratio	1:1	1:4	1:2
Vidicon area:			
- Vertical size (mm)	9	13.4	12.4
- Horizontal size (mm)	12	4.4	8
- Minimum line width (microns)	19	16	16

3.4 Computer aided picture handling

HOLMES is locally controlled via CAMAC by a MIK11 (LSI 11/2) mini-computer, which in addition executes those tasks which run continuously. The local computer is connected via two RS232 lines to a remote computer (VAX11/780), where the more elaborate tasks are executed and data are stored.

An operator controlled movement of the stages is executed via the MIK11, which counts the pulses from a trackball (x, y) and a wheel (z). If the ball or wheel turns fast, the number of pulses is increased non-linearly by the MIK11 program in order to increase further the speed of the stages.

The stage coordinates, the information from the functional keyboard and the terminal are transferred to the remote computer via the MIK11. In the other direction the remote computer may execute via the MIK11 stage movements. The graphic information is generated locally by the MIK11, which also lights the buttons on the functional keyboard and presents information to the operator on the terminal or the graphical monitor. Fig. 11 shows a photograph of the operator table and the TV monitors.

3.4.1 Track following

In the NA25 Experiment it is essential to check with high accuracy whether a track is straight or if it shows a decay or an interaction and whether it points to the primary or to a secondary interaction or to a decay point. The most efficient way to perform this test is to follow the track in a controlled way. To define a straight line in space two points on the track must be measured, one of which may be the interaction point itself. A line between the two points is defined by a point on the line and a vector with the components ax, ay and az. The program in the local computer uses a three by three matrix M, which is calculated by the steering program, to control the stage movement from the trackball (dx, dy) and the wheel (dz):

$$\begin{pmatrix} dx \\ dy \\ dz \end{pmatrix}_{stage} = M \times \begin{pmatrix} dx \\ dy \\ dz \end{pmatrix}_{ball,\ wheel} .$$

For a precise movement along the calculated line the stage is positioned on a point of the track and a matrix of the following form may be used:

$$M1 = \begin{pmatrix} ax, 0, 0 \\ ay, 0, 0 \\ az, 0, 0 \end{pmatrix} .$$

In the same way the stage movement may be confined to a plane in space. The matrix

$$M2 = \begin{pmatrix} ax, 0, 0 \\ ay, 0, 0 \\ az, 0, 1 \end{pmatrix}$$

defines a plane through the line, parallel to the z axis.

If the wheel (z) is not used one follows the line defined by ax, ay and az whereas by using the wheel it is possible to refocus the track. It turned out that the use of matrix M2 is the most convenient for track following and checking.

As the measurements and the checking are done using a fixed cross on the monitor screen, the check is independent of optical and electronic distortions due to the apparatus and depends only on the stage precision.

When following a track in space a deviation of the track from a straight line in the z direction can only be discovered by observing that the track goes out of focus. Only rather large deviations can be recognized in the z direction.

For the general three-dimensional movement the matrix is set to 1. However, if the place of focalisation shall remain constant when moving in the y direction, then the matrix

$$M3 = \begin{pmatrix} 1, & 0, & 0 \\ 0, & 1, & 0 \\ 0, & 1/2, & 1 \end{pmatrix}$$

must be used.

3.4.2 Graphic overlay

A simple graphical system is used, which is of considerable help to the operator. The graphic image is overlayed onto the video picture of camera 2. If P1 is a point in space, normally the position of an interaction, and P2 the current x, y stage position, then two crosses are displayed at the positions P1' and P2' on the monitor (fig. 12). A "fixed" cross is drawn at the position P1' on the monitor screen (it has a fixed position on the screen, not on the picture) and a second "moving" cross at the monitor position P2'. The fixed cross at the position P1' is used for centering. The position P2' is chosen such that the line through P1' and P2' is parallel to the line through P1 and P2 with a correction for the anamorphism of the camera (fig. 12).

The distance between P1' and P2' is calculated as a non-linear function of the distance between P1 and P2 with P1' = P2' for P1 = P2.

The position of the second "moving" cross P2' is continuously recalculated by the local computer, so that it follows instantaneously all movements of the x and y stages.

We demonstrate in fig. 12, with a few examples, how the graphic overlay system with the two crosses is used. In this example, the point P1 is taken to be the primary interaction point, and the squares show different parts of the photograph displayed on the TV monitor.

If the track comes from the interaction point (P1) then both the fixed cross (P1') and the moving cross (P2') will be situated on the track (fig. 12(a)). Fig. 12(b) describes a situation where the track has a kink and the moving cross is no longer situated on the track. It is of particular interest to identify tracks which do not seem to come from the primary vertex (fig. 12(c)). They could come from a badly visible decay very near to the primary interaction.

Even if the primary interaction point lies outside the displayed area it is possible to check whether a decay of a neutral particle into charged particles is associated with the primary interaction. This is done by centring the decay point onto the fixed cross and by checking if the outgoing tracks fall on each side of the moving cross (fig. 12(d)).

If no track pointing to the primary interaction is visible the two crosses indicate where the displayed part of the image is situated with respect to the interaction (fig. 12(e)). By moving the moving cross towards the fixed one, it is possible to return to the interaction point.

The x, y stages are exactly centred at the position where P1 was originally measured if both crosses are precisely superimposed. In this way one can check the quality of the measurement (fig. 12(f)).

Spurious tracks which pass sufficiently far from the vertex are easily identified (fig. 12(g)).

When an event is scanned this procedure is repeated with P1 as the primary vertex to start with and then at each of the decay points found.

These graphical checks are fast, but they work only on the projections onto the x, y plane and are affected by the distortions of the transfer lens and the camera. The great advantage is that they are independent of the magnification of the transfer lens.

3.5 Image treatment

With an image treatment system, new pictures can be created out of many single TV images digitized at different positions. This system has been used to produce a picture that covers a large area and has a larger magnification around the vertex than further away (fig. 13). This procedure is explained in detail elsewhere [5].

3.6 The HOLMES prototype

A simpler version of HOLMES was constructed using parts from the old CERN spiral reader. This prototype had many of the display facilities described for the final HOLMES, but it was mechanically much more simple and rather unreliable. It did however serve extensively for the NA25 Experiment and was for quite a while the only holographic scanning and measuring machine used for a large number of holograms.

4. PERFORMANCE

Particularly in depth the measuring precision depends on the picture quality and also on human factors. For isolated tracks a straight line fit to the measured point gave a precision of 6,4 and 2 microns (r.m.s.) for camera 1, 2 and 3 respectively in the x, y plane. The z coordinate was measured by focusing and gave a precision of 400, 200 and 150 microns (r.m.s.) for the three cameras respectively. When there is a large number of tracks in a small region, the precision in z can deteriorate quite considerably.

HOLMES has been in operation since the end of 1981. A total of 8000 holograms has been examined on it. Results on charm cross sections have been presented by the NA25 Collaboration [6, 7]. Fig. 13 shows an event with two decaying charm particles. The event is displayed using the image treatment system resulting in varying scales in the two dimensions in order to facilitate the observation of decays close to the primary vertex [5]. The same event is also shown in fig. 10(b) which is a photographic "collage" of three pictures.

5. SUMMARY

We have designed and implemented the scanning and measuring machine HOLMES used for in-line holograms produced in the bubble chamber HOBC. A total of 8000 holograms has been analysed on HOLMES. Both the mechanical and the electronic constructions have been very reliable.

An important feature in displaying bubble chamber particle interactions is the use of television monitors with overlay possibilities and computer aided picture treatment. Particularly for the detection of the charm particle decays, usually very difficult to observe, these facilities have been extremely useful.

Acknowledgements

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FIGURE CAPTIONS

Fig. 1 The holographic arrangement for the production of holograms.

Fig. 2 Production of a hologram by in-line holography.

Fig. 3 General layout of HOLMES.

Fig. 4 Schematic description of the optical arrangement for HOLMES.

Fig. 5 The use of transfer lens and spatial filter.

Fig. 6 Photographs showing the effect of the spatial filter: (a), (b) and (c) are the original images and (d), (e) and (f) are the corresponding filtered ones.

Fig. 7 Mechanical layout of the y, z and zoom stages (a) and the air flow arrangement for the air cushions (b).

Fig. 8 A photograph of HOLMES.

Fig. 9 Schematic drawing of an event without (a) and with (b) anamorphic display.

Fig. 10 A drawing and a photograph of an event without (a) and with (b) anamorphic display.

Fig. 11 Photograph of the operator table and the TV monitors.

Fig. 12 Schematic description of the overlay facility.

Fig. 13 A photograph of an event with two decaying charm particles. The scales are very different in x and y.

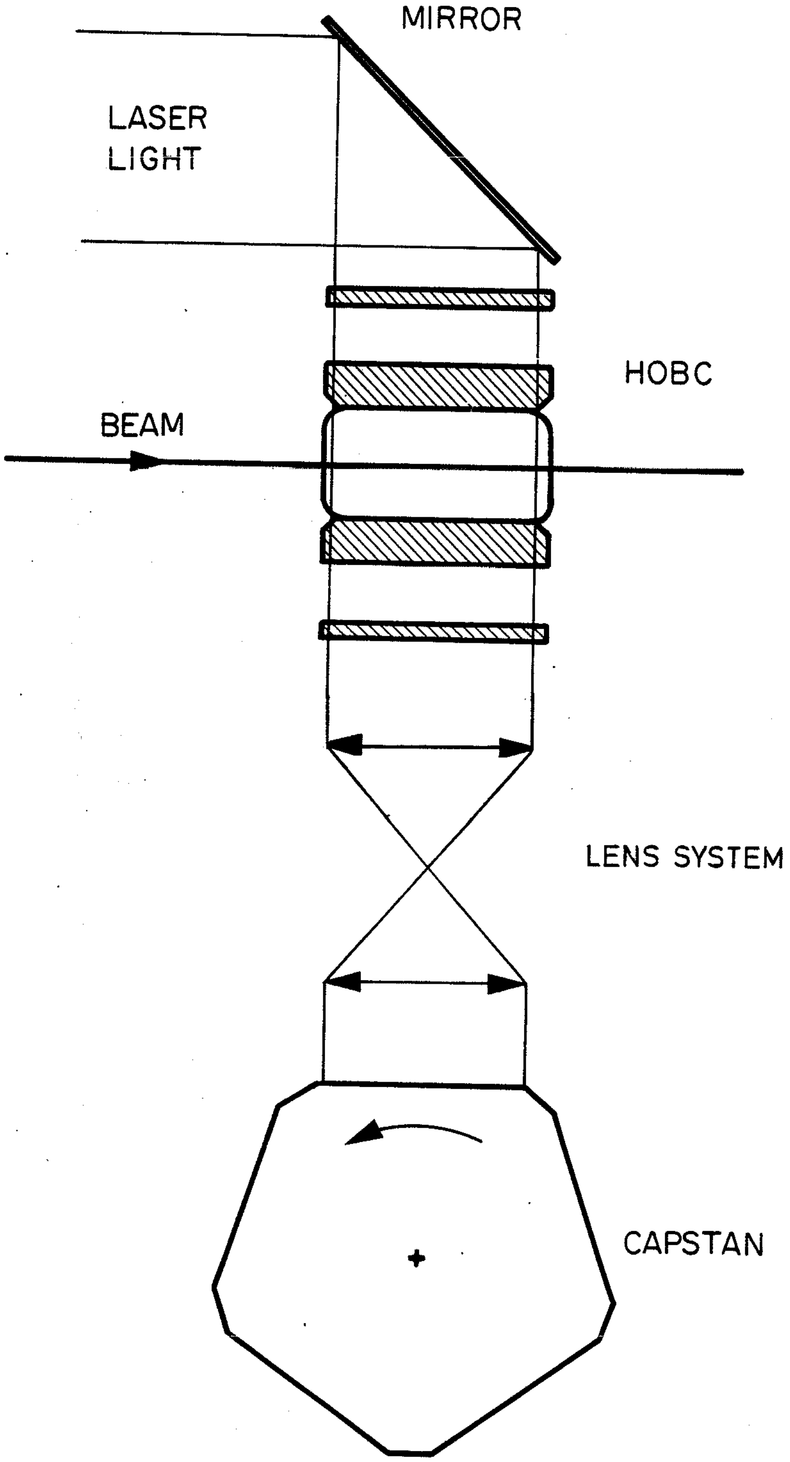


Fig. 1

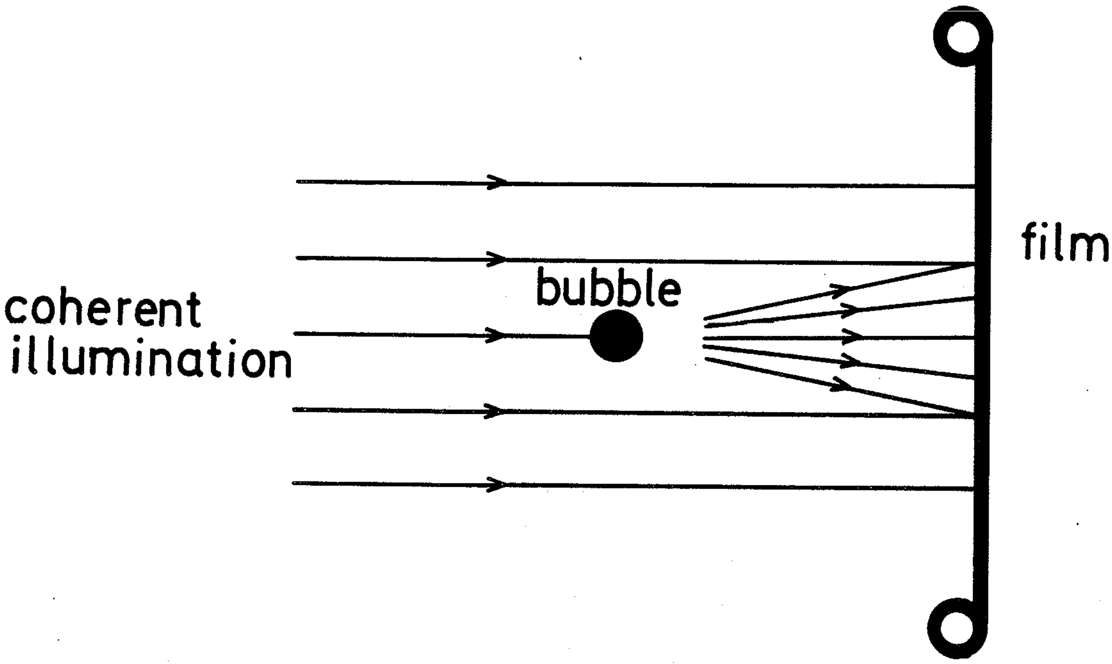
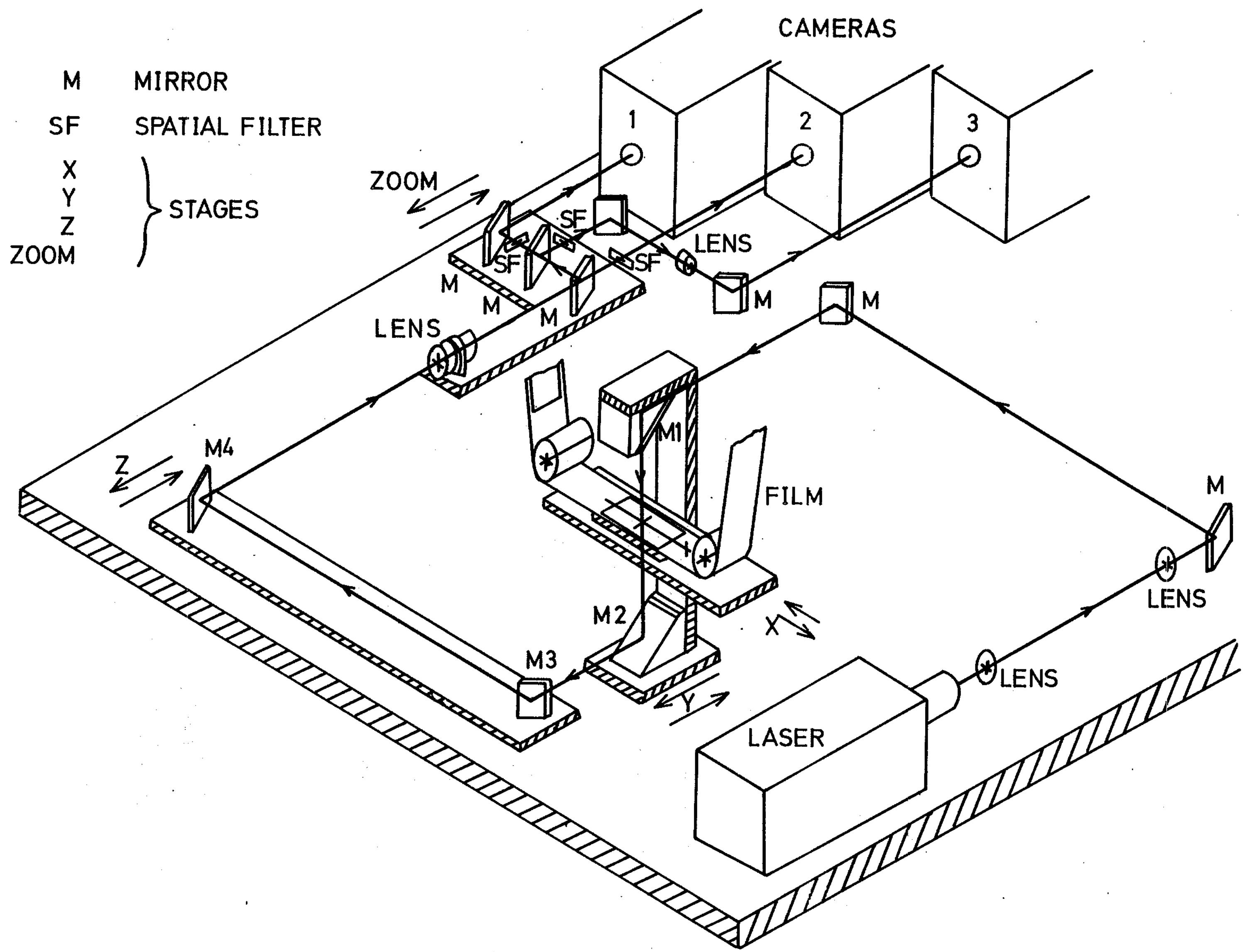
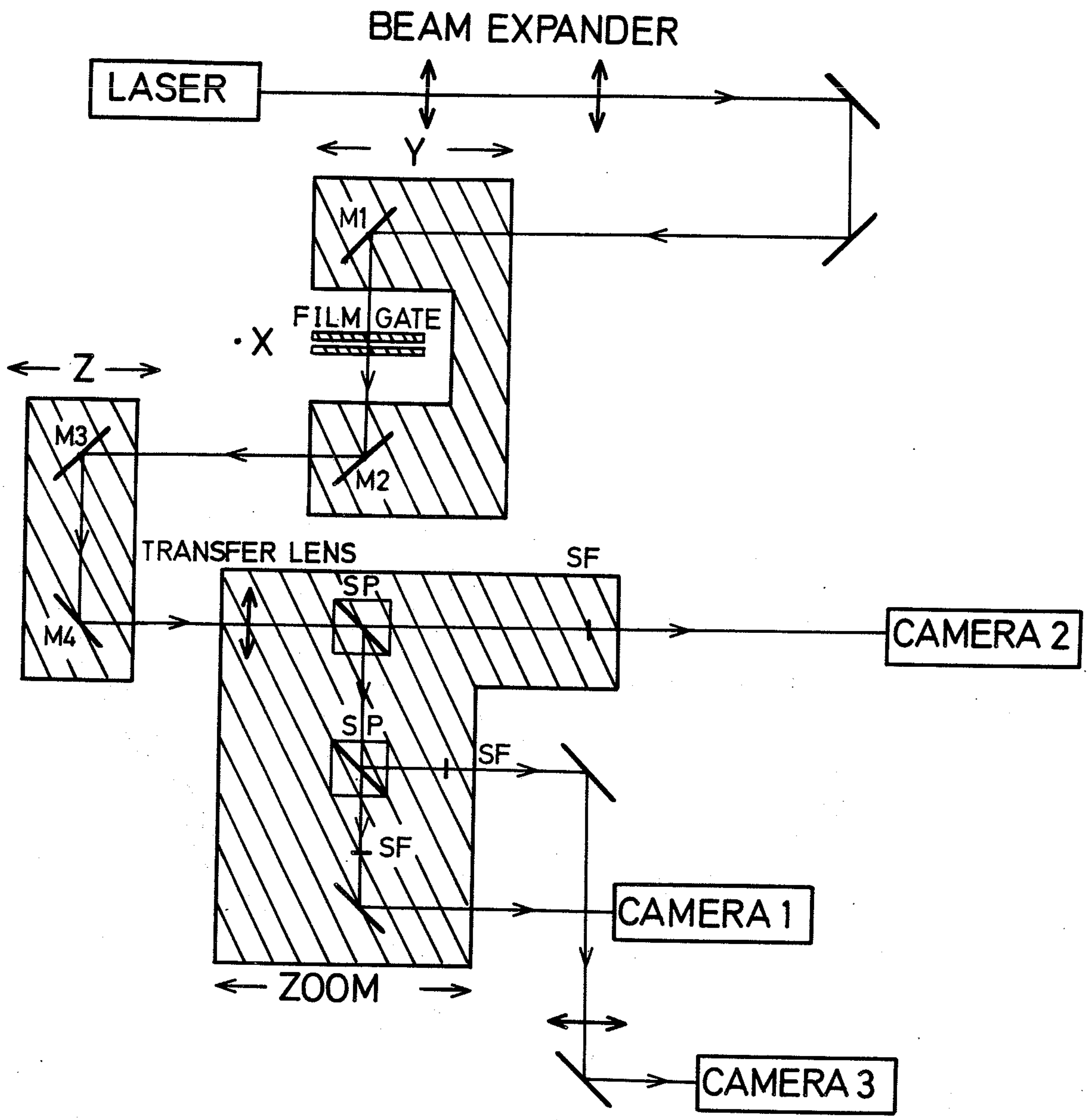


Fig. 2



CAMERAS
M MIRROR
SF SPATIAL FILTER
X
Y
Z
ZOOM
STAGES
1
2
3
ZOOM
SF
SF
SF
LENS
M
M
M
M
M
LENS
M4
Z
M1
FILM
M
LENS
M2
X
M3
Y
LENS
LASER

Fig. 3



SF SPATIAL FILTER

SP SEMITRANSPARENT PRISM

Fig. 4

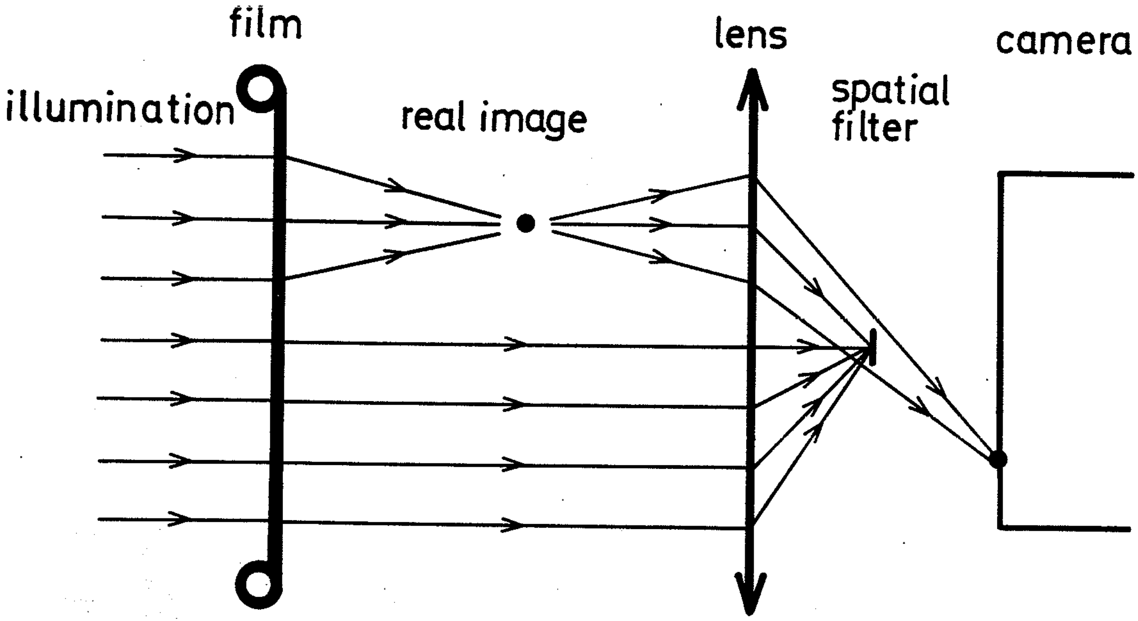


Fig. 5

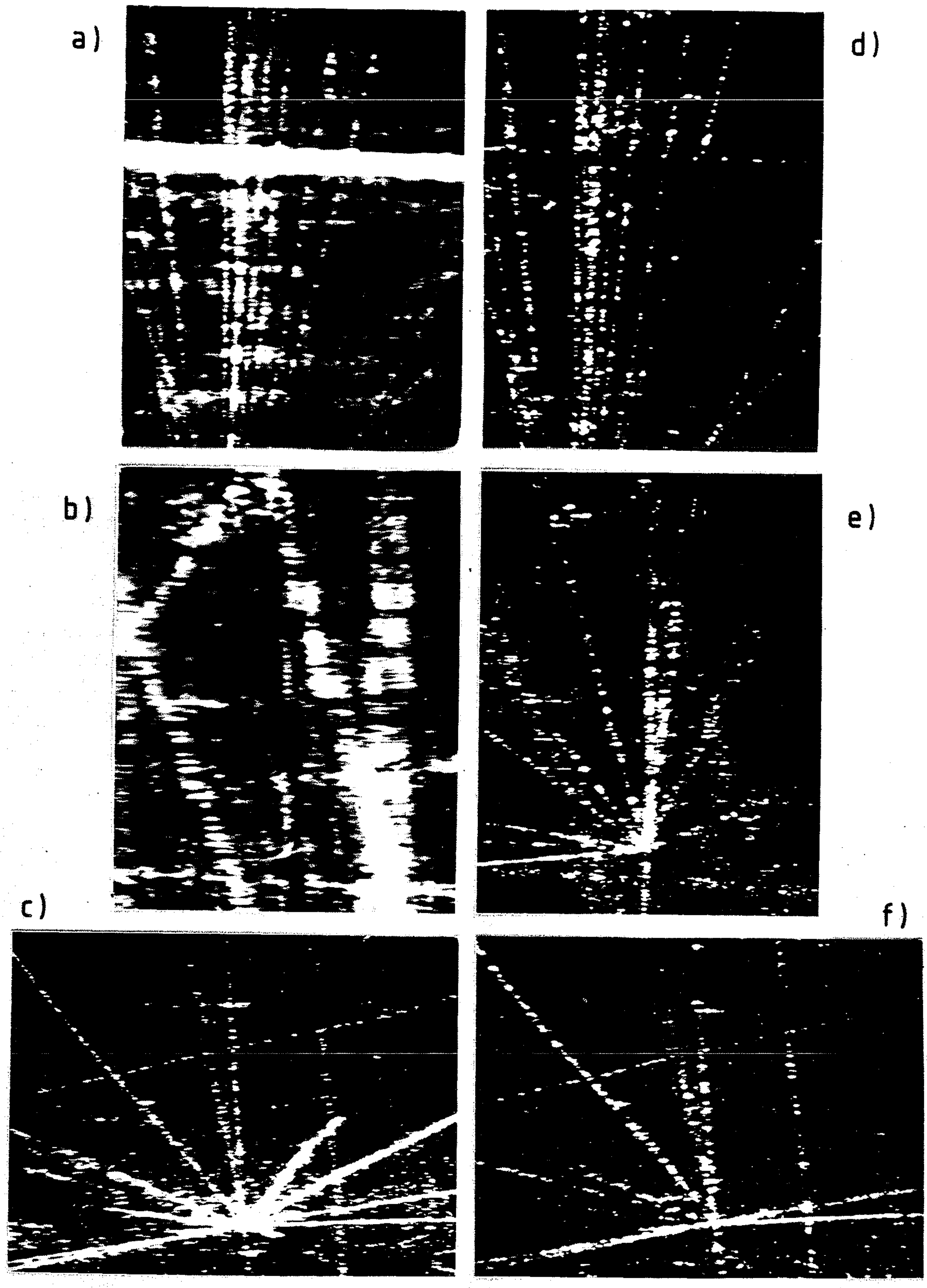


Fig. 6

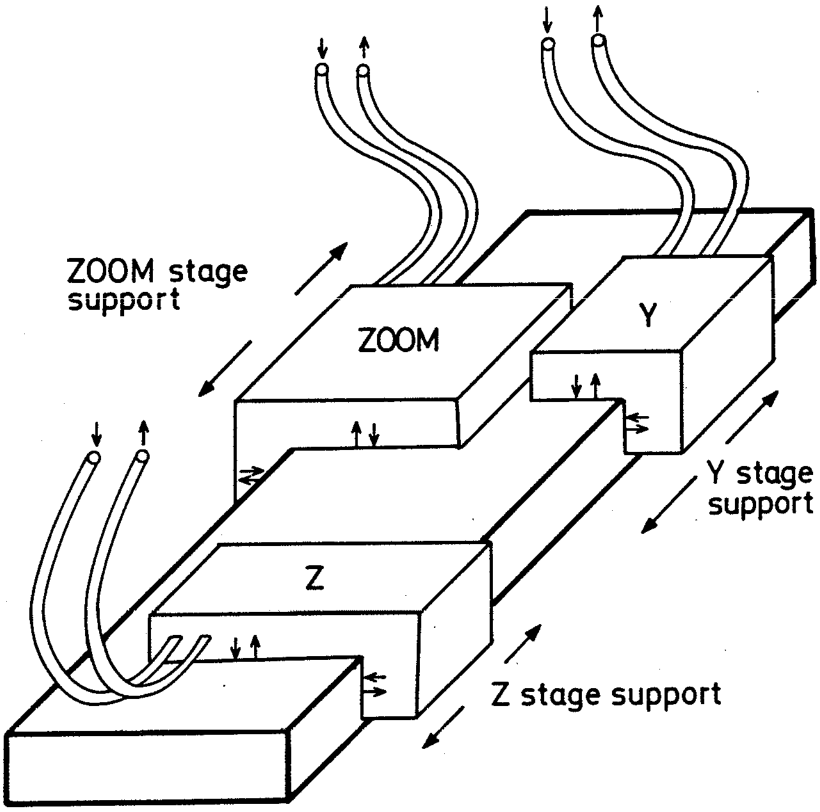

ZOOM stage support
ZOOM
Y
Y stage support
Z
Z stage support

Fig. 7a

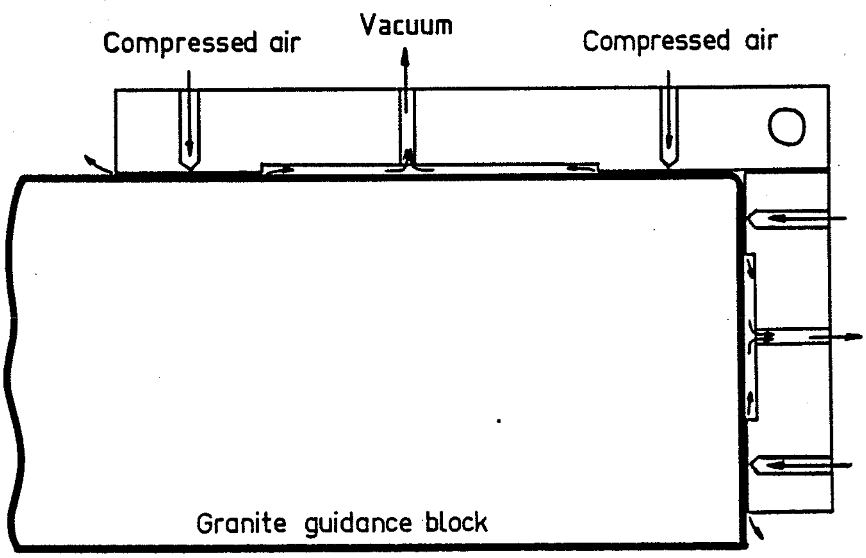

Compressed air
Vacuum
Compressed air
Granite guidance block

Fig. 7b

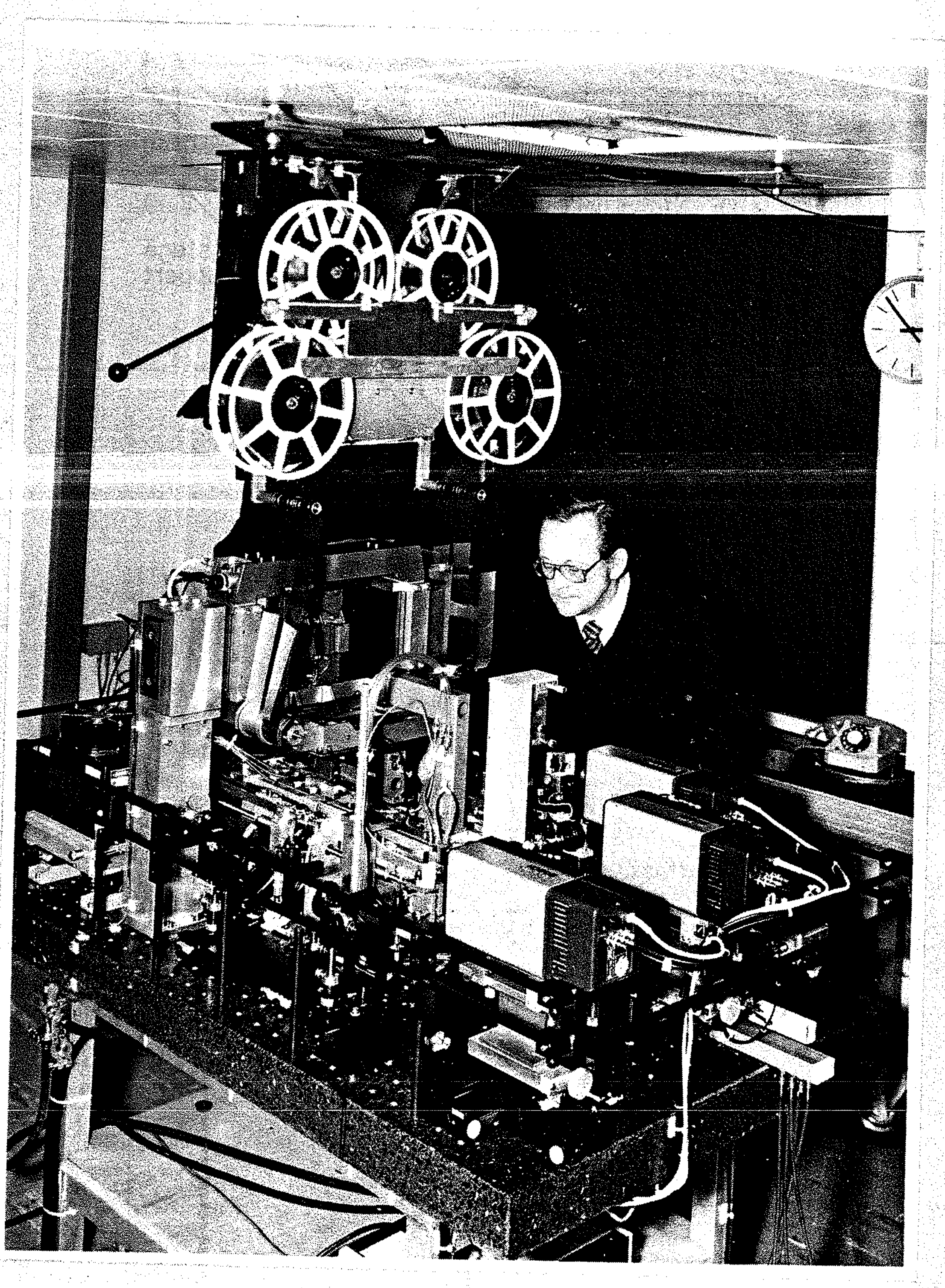


Fig. 8

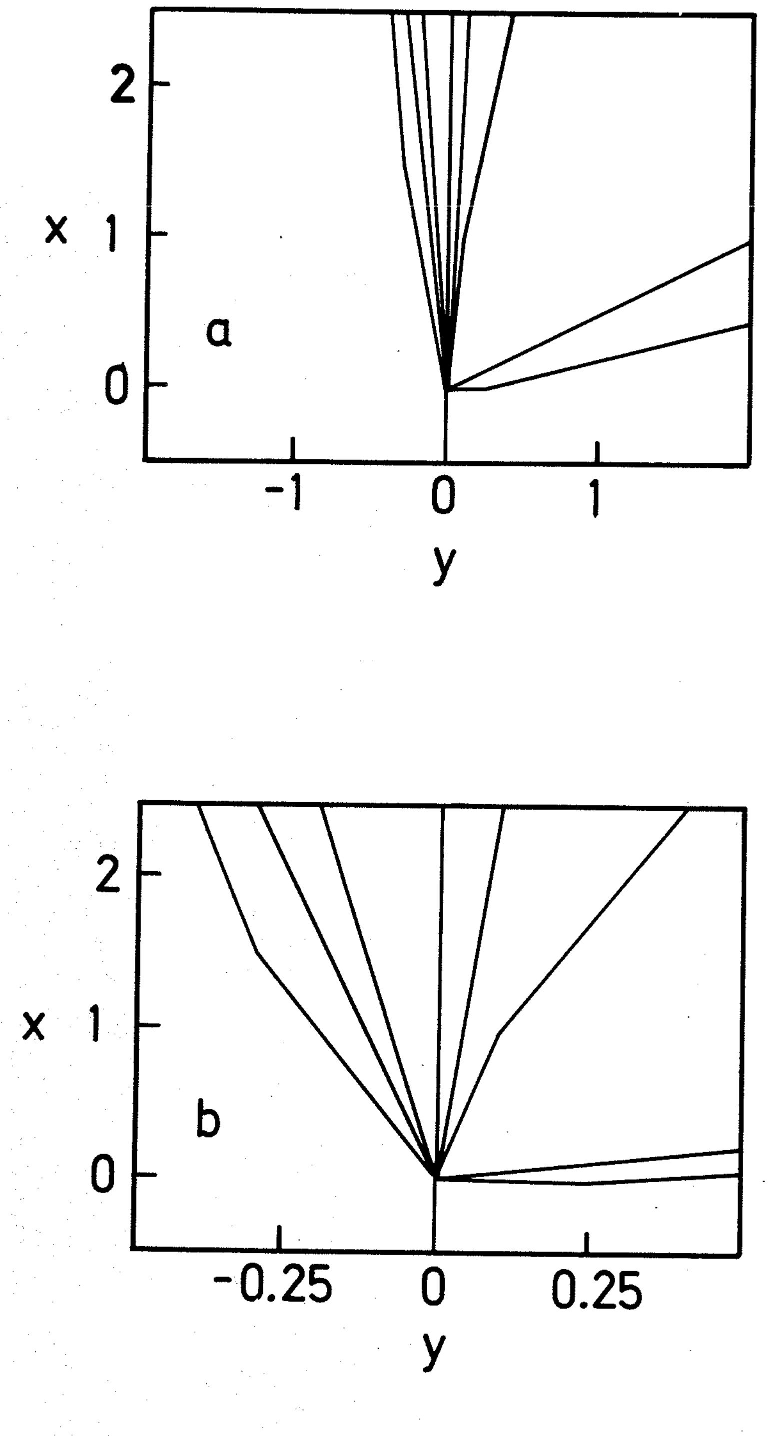
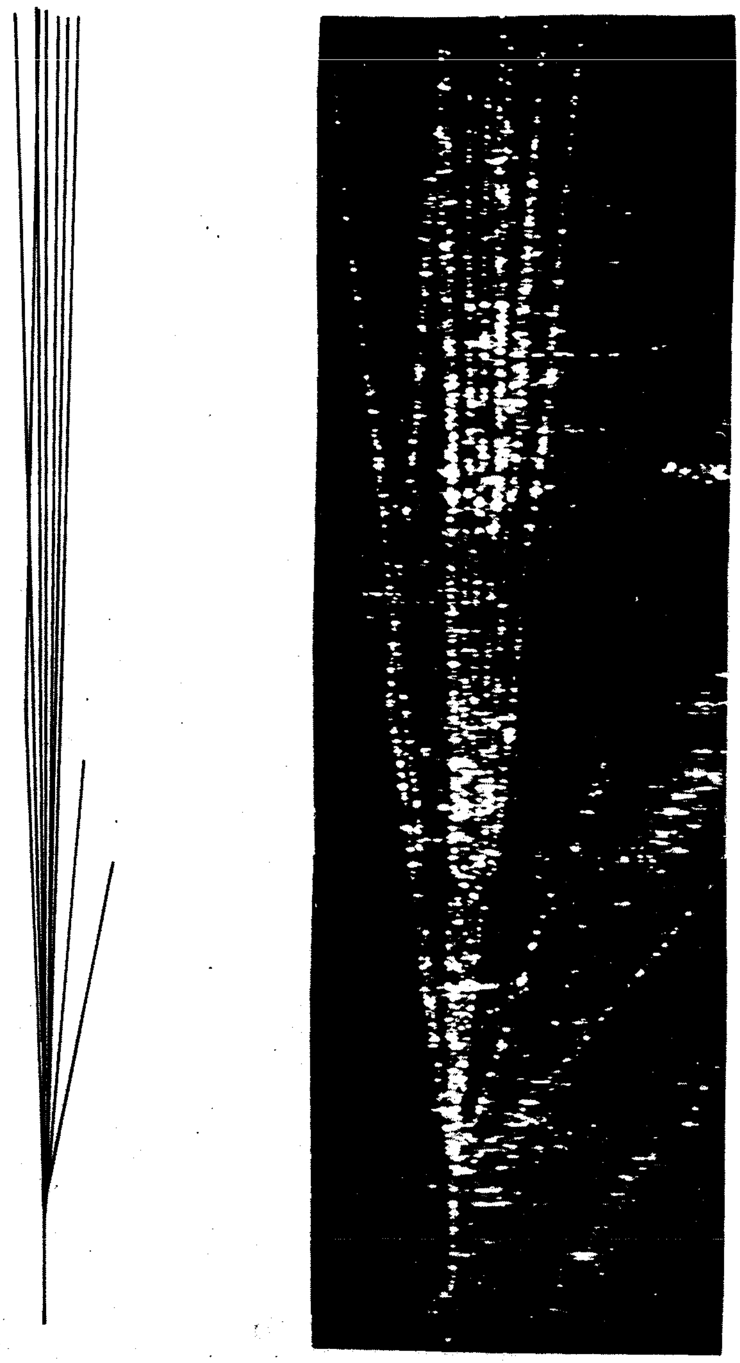


Fig. 9



1 : 1 1 : 4

(a) (b)

Fig. 10

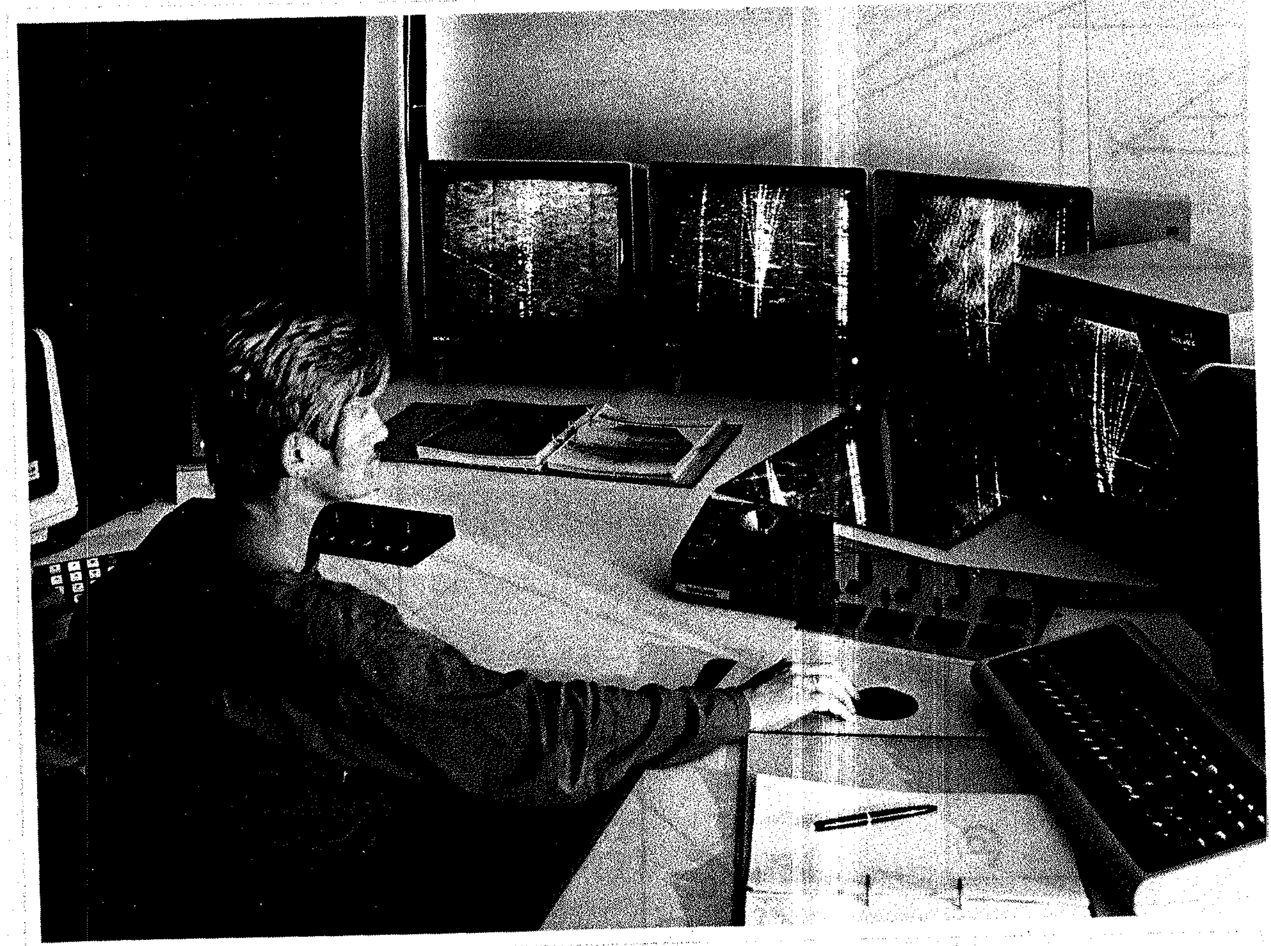


Fig. 11

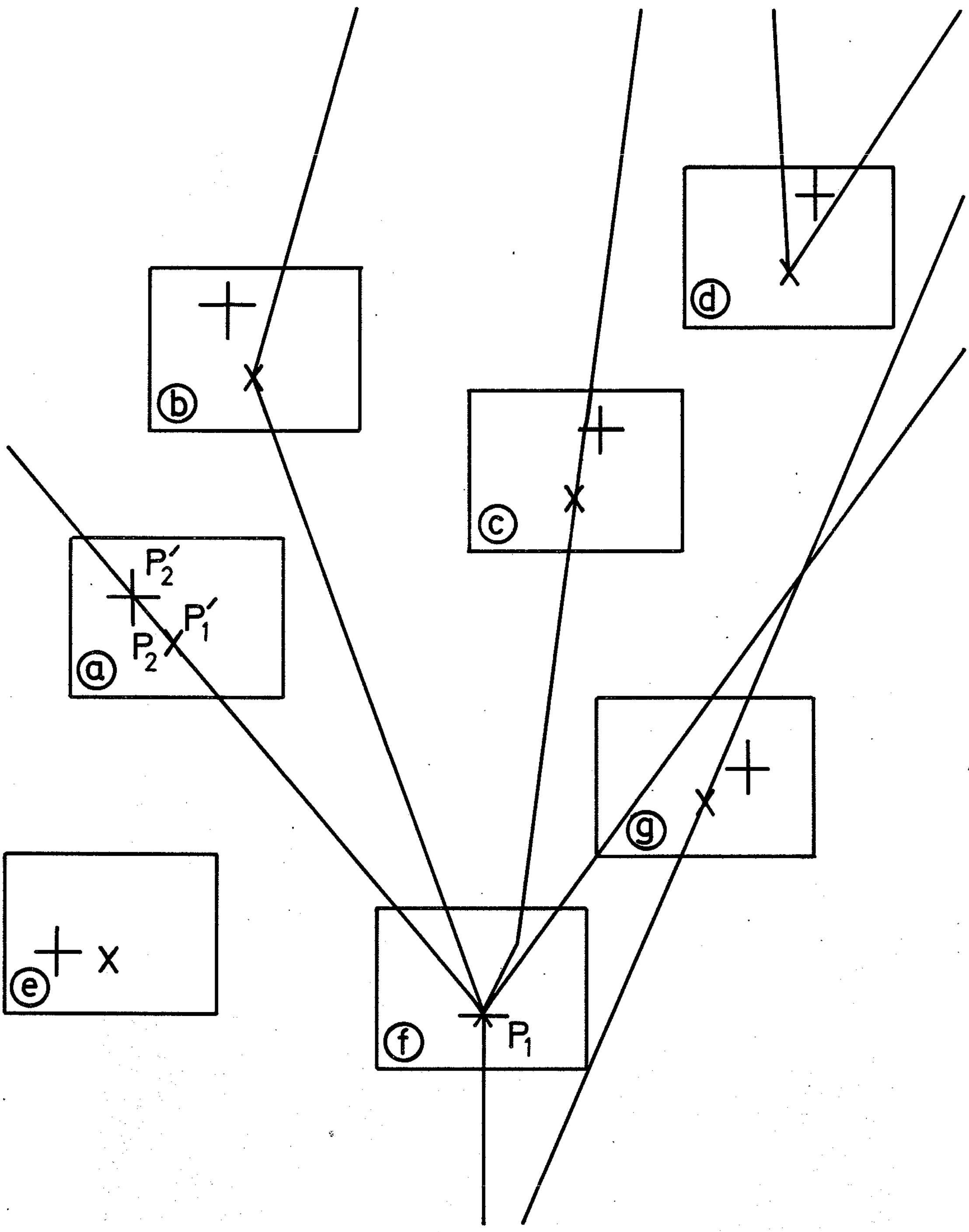
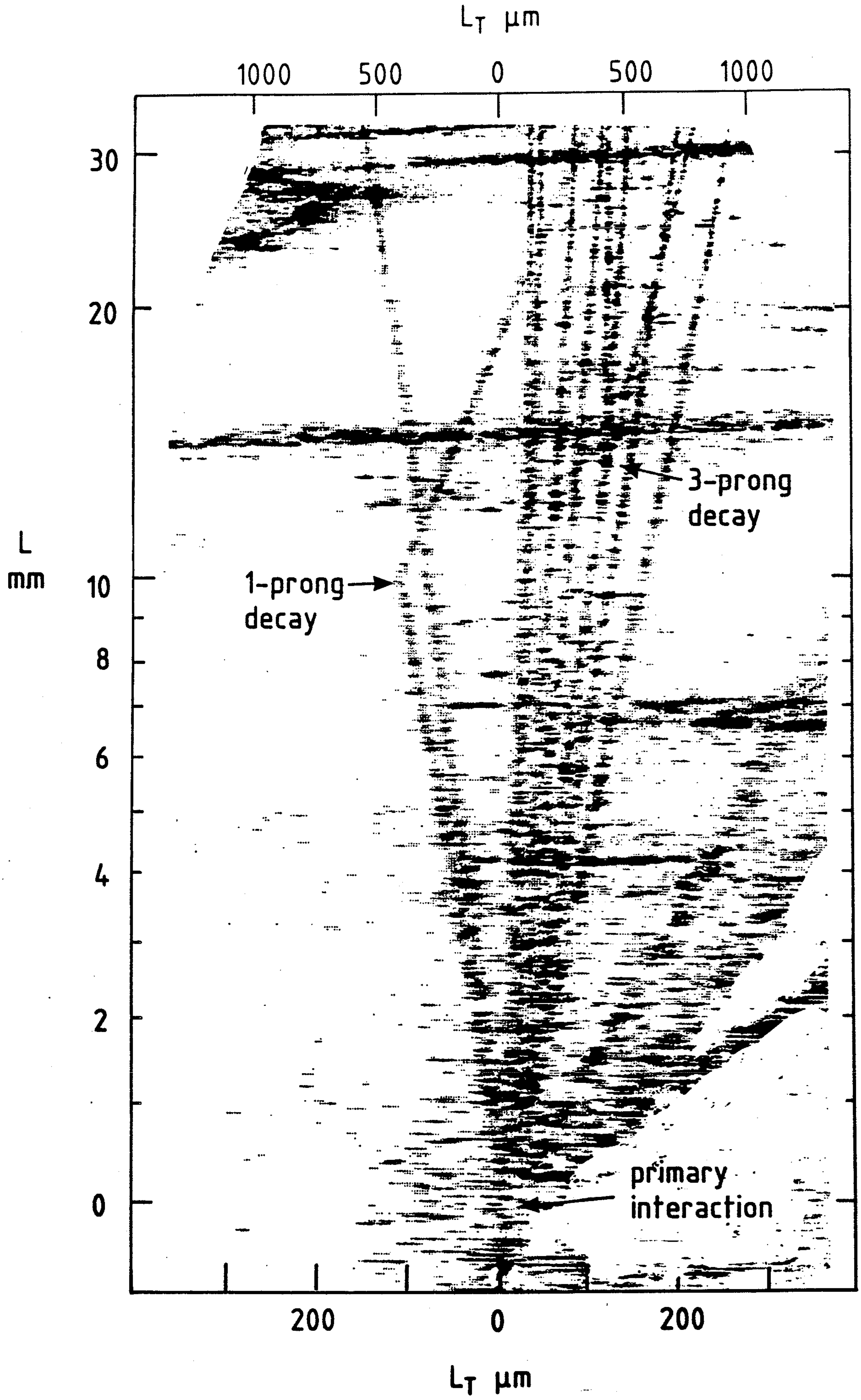


Fig. 12



L_T μm
1000
500
0
500
1000
30
20
L
mm
10
8
6
4
2
0
3-prong
decay
1-prong
decay
primary
interaction
200
0
200
L_T μm

Fig. 13