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ЛАБОРАТОРИЯ ВЫЧИСЛИТЕЛЬНОЙ ТЕХНИКИ И АВТОМАТИЗАЦИИ

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MEASUREMENT OF BUBBLE CHAMBER FILM USING HPD

* Лекция, прочитанная в Школе ОИЯИ по применению электронных вычислительных машин в задачах экспериментальной физики г. Алушта, Крым, СССР, 5-19 мая 1968г.

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Дубна 1968

Широкое внедрение электронных вычислительных машин в различные звенья физического эксперимента за последние годы вызвало определенный интерес со стороны физиков-экспериментаторов к вопросам вычислительной техники и программированию. Персонал физических лабораторий при подготовке экспериментов или обработке экспериментальных данных вынужден (в большинстве случаев самостоятельно) осваивать технику ЭВМ и методы работы на вычислительных машинах.

При всем многообразии материала как по самим вычислительным машинам, так и по вопросам программирования, в процессе такой работы возникают естественные трудности, связанные, главным образом, с ограниченностью литературы, рассчитанной на физика-экспериментатора или на лиц, занимающихся развитием методических вопросов экспериментальной физики. Если учесть при этом, что методика использования ЭВМ в экспериментальной физике быстро совершенствуется, то будет понятен интерес со стороны физических институтов к летней школе Объединенного института ядерных исследований - "Применение ЭВМ в задачах экспериментальной физики".

Школа проводилась Лабораторией вычислительной техники и автоматизации ОИЯИ (директор - член-корреспондент АН СССР проф. М.Г.Мещеряков) в г. Алуште (Крым) с 5 по 19 мая 1968 года.

Программа школы наряду с основополагающими вопросами включала также лекции по некоторым конкретным современным методикам. Для чтения лекций были приглашены ведущие специалисты из Объединенного института ядерных исследований, институтов стран-участниц ОИЯИ, а также коллеги из европейских исследовательских центров - ЦЕРНа (Швейцария) и Сакле (Франция).

Не имея возможности опубликовать весь материал, ректорат Школы подготовил к изданию отдельные лекции, сохранив, в основном, их в том виде, в котором они были представлены авторами.

Лиц, интересующихся лекциями в полном объеме, мы адресуем в библиотеку ОИЯИ, где находится полный сборник прочитанных в школе лекций: "Применение ЭВМ в задачах экспериментальной физики".

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Г.ЗАБИЯКИН

Отпечатано методом ксерокс-ротапринт с материалов, подготовленных ректоратом Школы.

INTRODUCTION

This paper will attempt to give an idea of the way in which the HPD or mechanical flying spot digitizer is used now to measure large numbers of bubble chamber pictures. A new programming development (minimum guidance) will also be described briefly. The emphasis will be on the computer programs and work at CERN in particular.

Unnecessary detail will be avoided, because many of the programs and techniques described have been the subject of lengthy papers themselves. The missing detail in most cases can be found in the references, which are generally to conference papers or other miscellaneous reports. There is also the CERN FSD Bubble Chamber Program Manual[1], and the chapter by P.V.C. Hough in a book on "Bubble and Spark Chambers"[2].

THE HPD

The first tests with the prototype HPD on-line to an IBM 709 computer were reported on in 196.[3]. There are now two HPD's at CERN on-line to the CDC 6600 computer, namely the earlier HPD 1 which has been used for two 81 cm chamber experiments and several spark chamber experiments, and the larger and faster HPD 2 which is now being used to measure a 2 m chamber experiment. In what follows, only HPD 2 measuring 2 m chamber film will be referred to, unless stated otherwise. A full description of HPD 2 is given in a CERN report which has just been published[4].

The HPD gives a map of the picture constituting one of the stereo views of the bubble chamber in digital form to the computer. A mechanically generated flying spot of light, smaller than a bubble, sweeps the picture at the same time as a precision stage carrying the table moves underneath at right angles to the direction of sweep of the spot. The effect is to cover the picture in a TV-like raster scan with separation between the lines usually about 60 μ, the lines being inclined at a calculable small angle. The method of generating the spot is shown in Fig. 1, and a diagram of the raster scan is shown in Fig. 2. It will be noted that the stage can move in a direction along the length of the film (normal scan) and also at a right angle to this (abnormal scan). The abnormal scan is used for tracks which make too small an angle with the scan-line in the normal scan.

At the beginning of each scan-line the two stage coordinates are read out, and then during each sweep a W-coordinate is read out whenever the spot encounters an object such as a bubble, a fiducial mark arm, a scratch etc. Thus the computer sees the picture as a series of coordinates for each scan-line: . . . . . .

$$\ldots\ldots\quad X, Y, W_1, W_2, \ldots W_N, W_{max} \quad \ldots\ldots$$

where X,Y are the stage coordinates (one of them will remain constant) and the W's are the spot coordinates. The stage least count (or quantum of length) is 2.0 μm and the spot least count is 1.6 μm. The result of plotting the digitizings of a typical normal scan can be seen in Fig. 3.

A normal scan covering a 150 x 50 mm frame takes about 6 sec, and may contain about 100,000 digitizings. An abnormal scan covers an area 50 mm x 50 mm. Overall measurement rates will be discussed later; there are several other factors which appreciably reduce this.

GATING AND FILTERING OF TRACKS

The digitizings are at present reduced by about a factor of ten on input to the computer by selecting for later analysis only those which lie in the vicinity of tracks of interest or in boxes

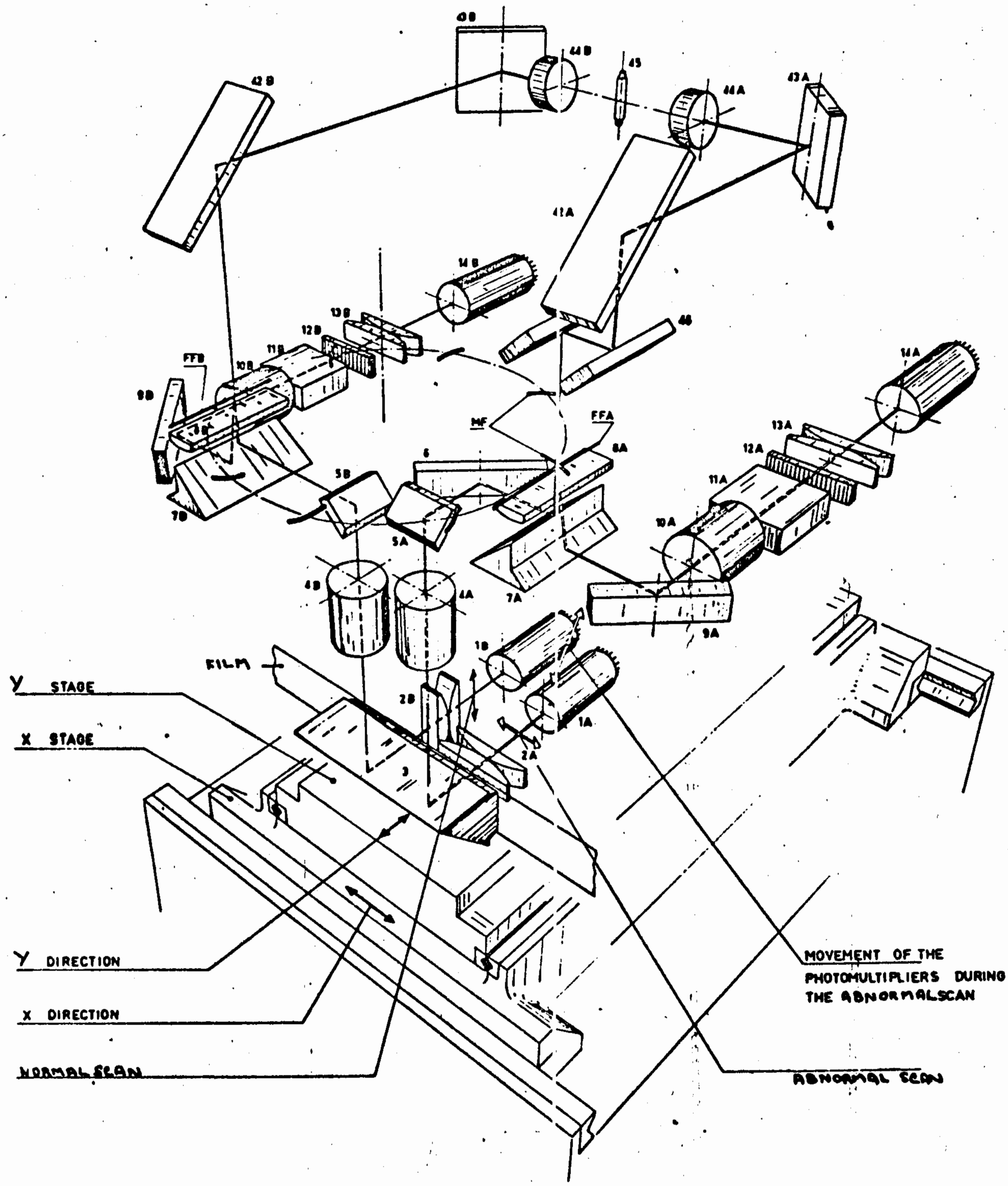

Fig. 1 : Schematic diagram of the HPD

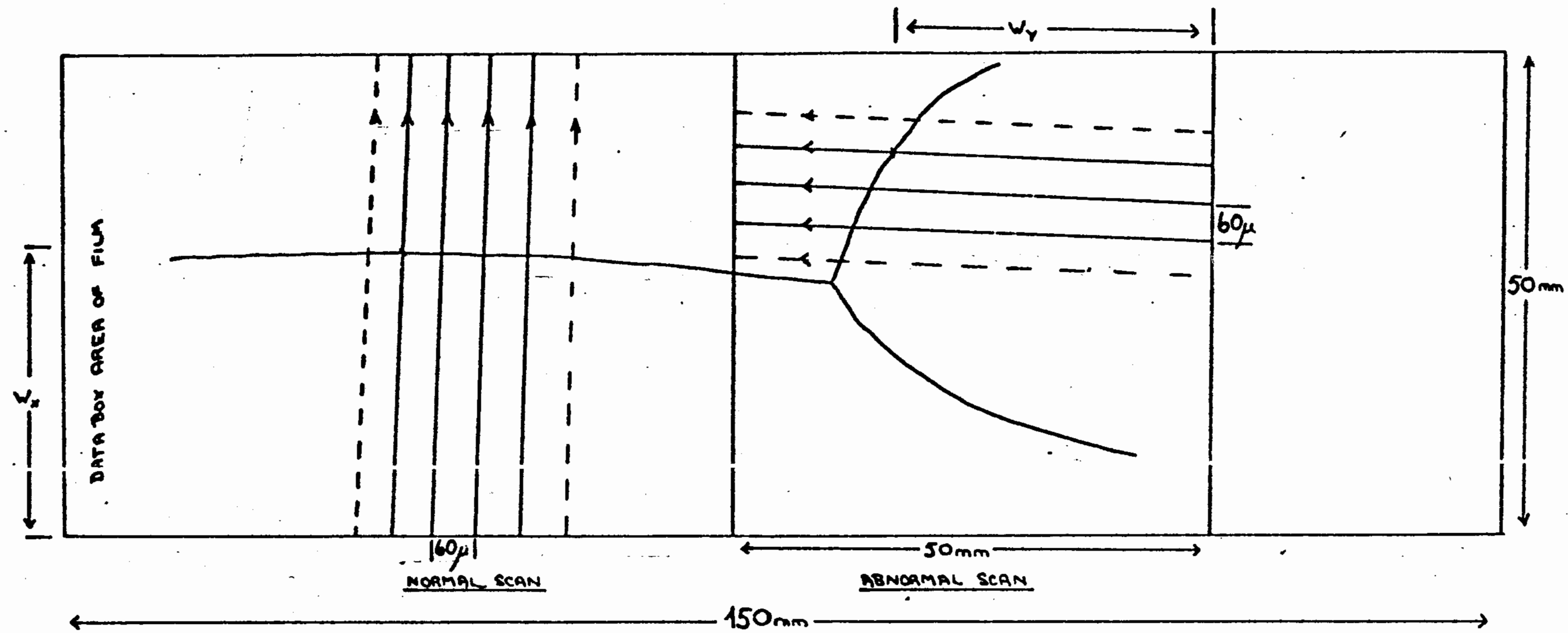

Fig. 2 : Diagram of HPD raster scan

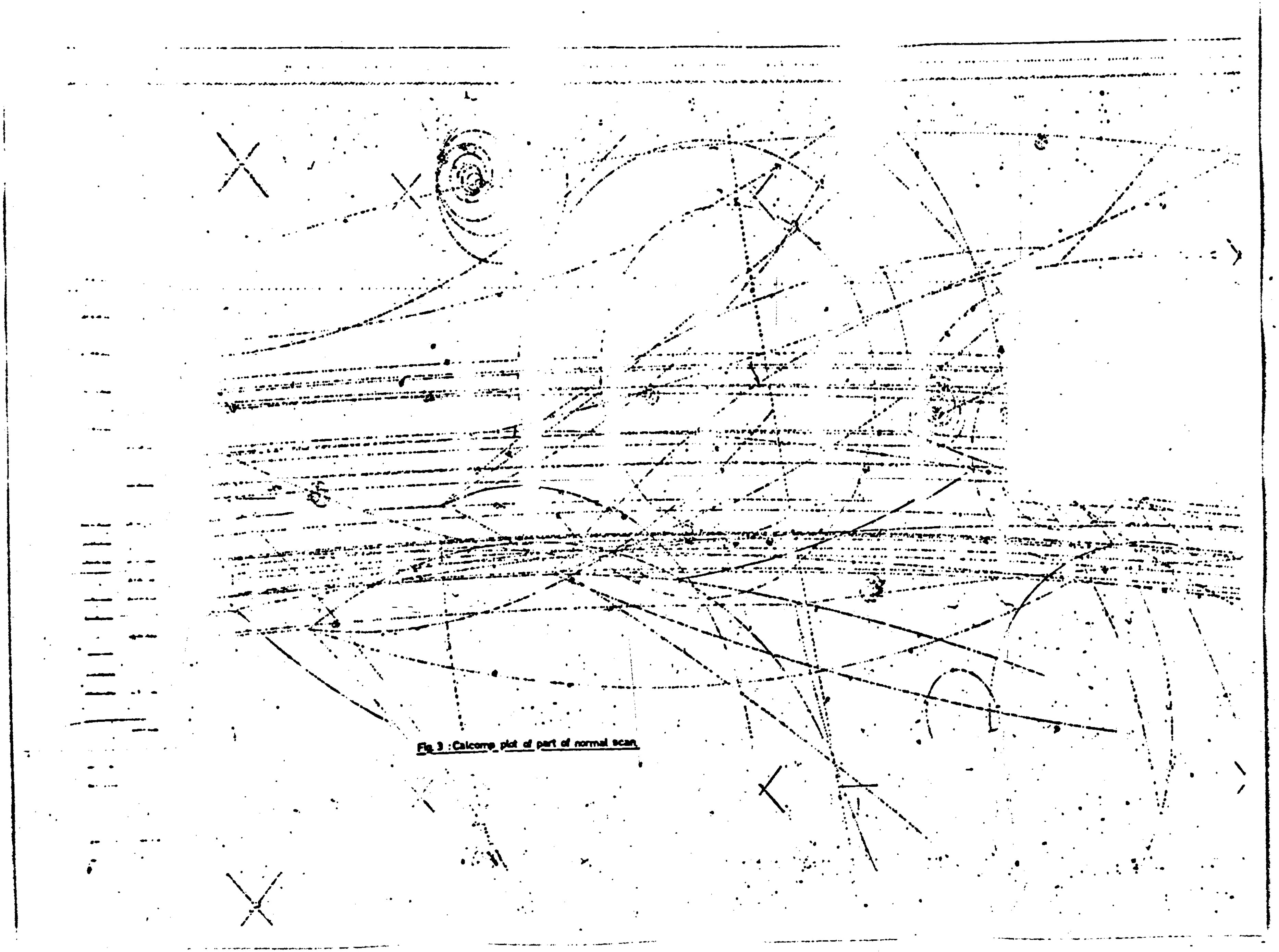

Fig 3 : Calcomp plot of part of normal scan.

around fiducial marks. The tracks to be measured are indicated to the program by previously rough-digitizing manually three points on each track (i.e. at the beginning, middle and end) with a precision of about 100 µm. This rough-digitizing operation is performed at the Milady scan-tables as the film is being scanned for relevant events.

The data reduction operation is called gating. It is done by fitting a circle through the three points, thus defining a "road" of half-width 256 least counts (or 400 µm) about this circle; only digitizings which lie within such roads are kept. The gated road contents are then transmitted to another program for filtering out of the interesting tracks from the immediate background within the road. Fig. 4 shows printer plots of short sections of typical roads. All digitizings within the road are plotted relative to its edge, thus in effect straightening out the circle.

Finding an algorithm for gating is straightforward. The only problem is to write coding which will not take too much computer time per digitizing. Filtering techniques, on the other hand, have had to be developed and then refined until their performance on a large sample of events proved satisfactory. The requirements are stringent and it was not obvious at the start that they could be met. On four-prong events the failure of one track-view in 200 leads to more then 5 % event failure. In the present experiment the event failure rate is about 25 %. There are a variety of causes - mainly errors at the scan table - filter errors contributing only a few percent, though sometimes, for example in the case of a badly aligned road, it is difficult to assign the blame uniquely.

The road-filtering program at CERN was developed in collaboration with RHEL, and is described in several reports[5,6,7]. It is worthwhile summarizing here the main features, though if we had to write a new road filter program today we would almost certainly do it somewhat differently, treating it as a special case of a later development (Minimum Guidance).

The road is divided up lengthwise into slices of 32 or 16 scan-lines depending on the curvature. Within each slice, track elements are sought by looking for pulses in a histogram of the W-coordinates relative to a road edge. When such a pulse is found, the bits in it are averaged to give a master point. In the first slice, the road edge used for the histogram is that of the Milady road, and a relatively coarse histogram is used. The track is followed from slice to slice always making use of the master points previously found both to compute a new road-edge in the next slice and also to predict the position of the next master point.

Needless to say there is a complicated logic to take care of the various unpleasant situations which can occur, for example closely spaced parallel tracks, tracks crossing over and "shadowing" each other (due to the dead time of the digitizing circuit) tracks which fade out and reappear etc., etc. Short tracks are treated specially; as their angle is less well defined, histograms with edges at different angles are used. Bubble density information is obtained from the number of hits in the pulse divided by the number of scan-lines in the slice.

Fiducial marks are also found by histogramming; the angle of each arm is assumed well known beforehand, so that a straight line at this angle can be used as a "road" edge to find a given arm. The location of the fiducial marks in this way is in fact done in the GATE program immediately after measurement of the normal scan. If a sufficient number of them are not found the frame is re-measured.

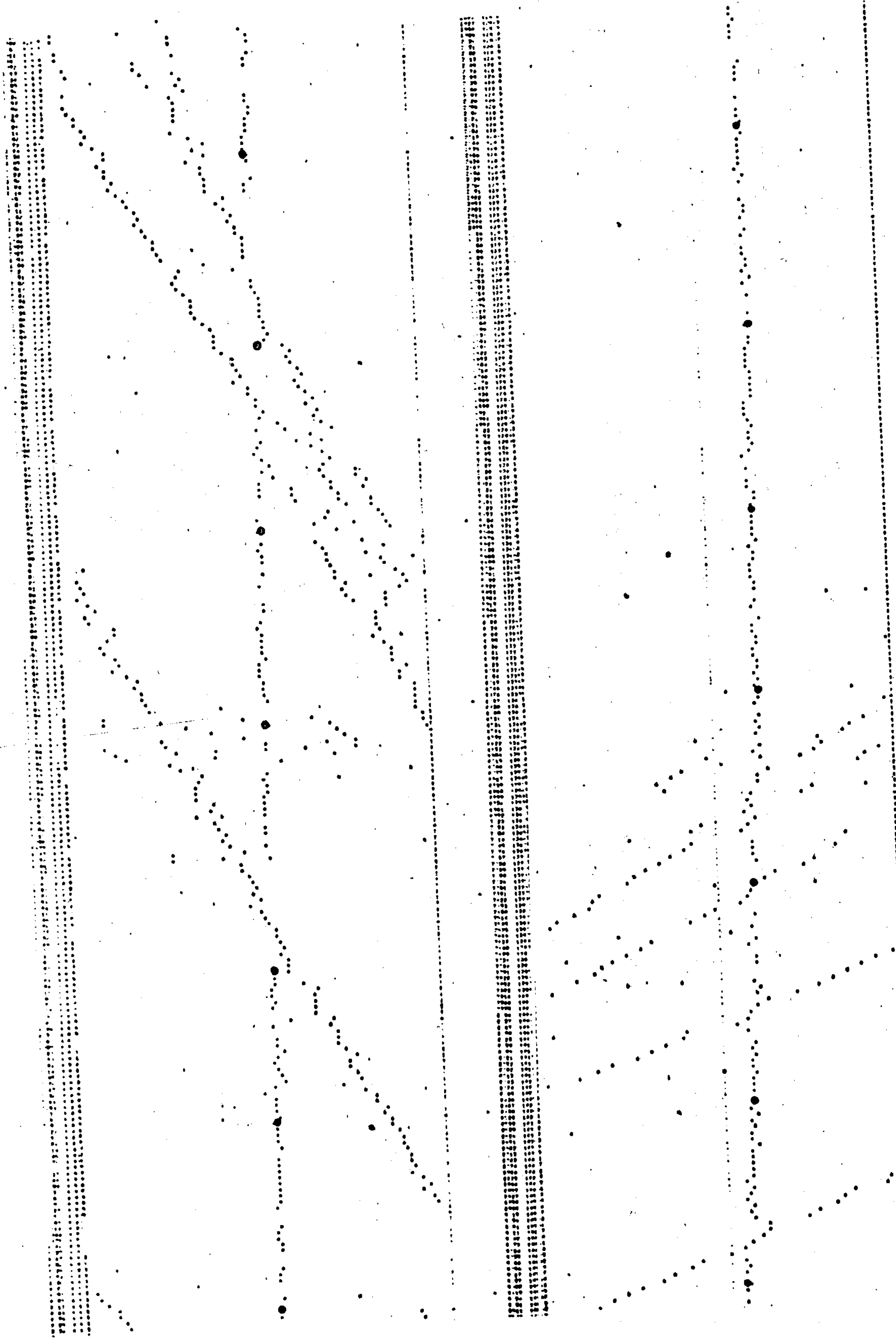

Fig 4 : Parts of Typical Roads

THE PROGRAM CHAIN

The HPD bubble chamber analysis system at CERN consists of the chain of programs shown in Fig.5a. Data is passed from one program to another via magnetic tape. The programs are written in Fortran whenever possible except for some routines where computer speed is important, for example in gating. There is a tendency for most laboratories to use a similar sub-division of programming tasks with the HPD. The basic functions of the different programs of the chain are almost evident.

The MIST program sorts, checks and performs preliminary calculations on the data output by the Milady scan-tables. MIST decides, for example, when a track or part of a track should be measured in the abnormal scan. It also outputs an index tape for accounting. In a new development, the Milady tables are being attached to a small computer (IBM 1130) in which all the preliminary checking will be carried out.

GATE is the program which controls the HPD and, as its name implies, gates the digitizings into roads for the FILTER program. The output from FILTER consists of a set of average points, and the bubble density information. SMOG combines the normal and abnormal scans of the same event-view, and also merges the event-views from the different rolls of film.

Track-matching means the association of track-image from the different views. Doing this automatically saves much time and effort, and avoids errors, at the scan-table. The geometry program[8] (THRESH) is very nearly the same as the standard version used for manual measuring machines. It now makes mass-dependent points for each track[9].

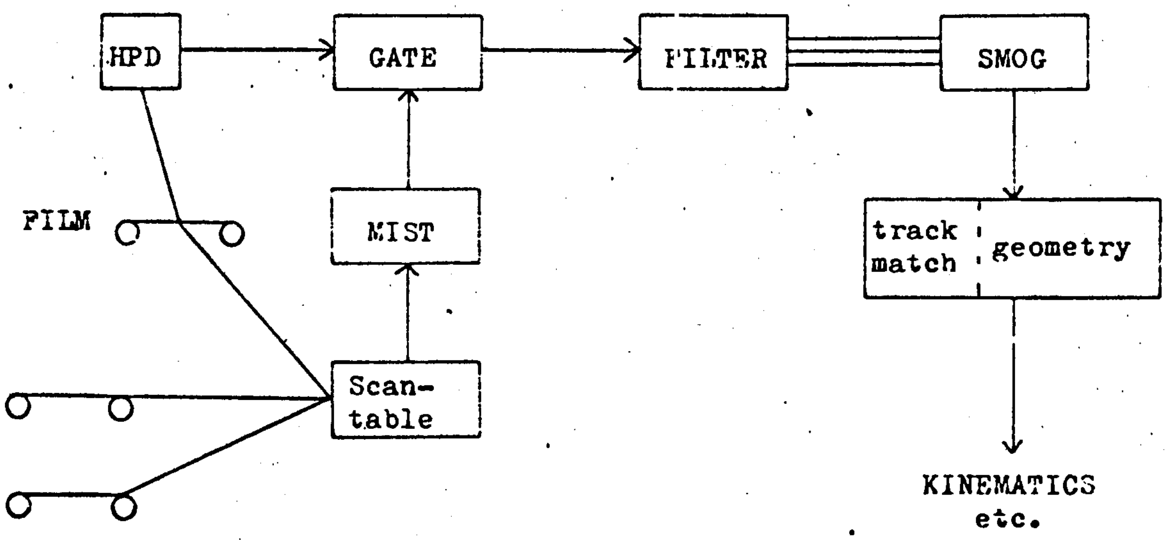

Fig. 5a

HPD program chain for road guidance

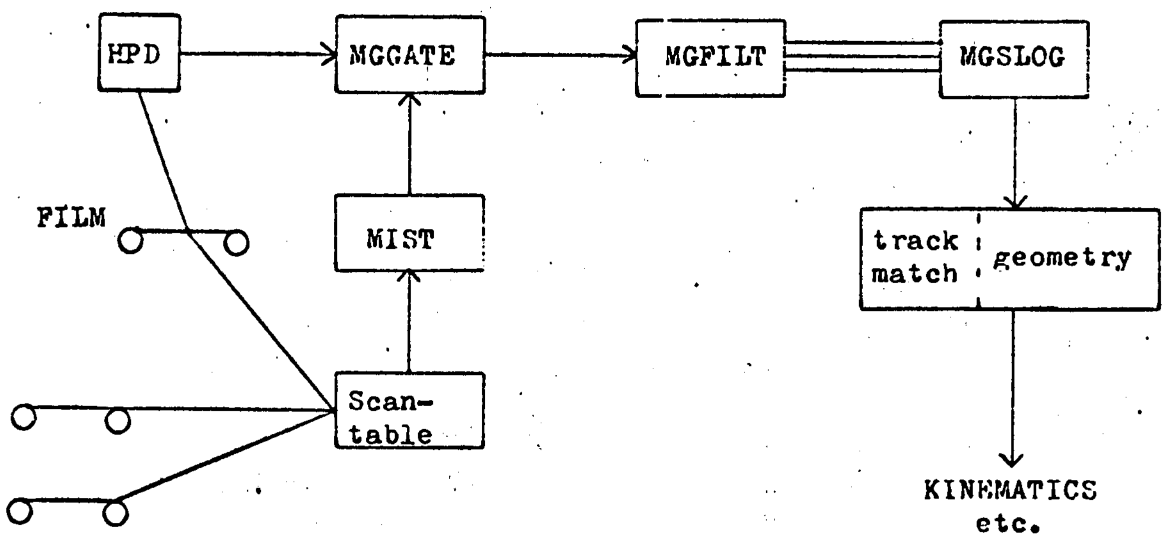

Fig. 5b

HPD program chain for minimum guidance

The above description of the programs cannot give an adequate idea of the effort required to develop such a production system. There is much detailed work concerned for example with the transformation from the coordinate system of the scan-table to that of the HPD, with the detection of nearly all possible human and hardware errors, with the problems created by poor quality rolls of film, etc. etc. There is considerable incentive to make use of work already done by other groups where this is possible. An important point is that all these programs are under continuous development and care must be taken when changes from one affect an other.

IONIZATION

One of the advantages of the HPD is its ability, in principle, to give bubble density information to help choose between different hypothetical mass assignements at the kinematics stage. This is possible because of the small spot size and the fact that the track is sampled on scan-lines which are separated by only a few bubble diameters.

The basic method was first developed by Strand[11]. It has also been dealt with in several papers since then; a fairly concise description is given by Hough[2]. The procedure will be sketched here extremely briefly.

The basic relation used is :

$$ka = \log T/(T-H) = T/M$$

where :

- k = bubble density (i.e. bubbles per mm)
- a = apparent bubble diameter
- T = number of scan lines intersecting the track
- H = number of hits (i.e. number of digitizings in histogram pulses)
- M = number of misses (= T-H)

From the description of filtering given earlier it should be evident how H and hence M, is obtained from the histogram pulse. The quantity ka so derived is corrected for non orthogonality of the track to the scan-line, and for inclination of the track in the chamber with the film plane, to give a value in the chamber. The values from the three separate views of each track are combined together to give ba and its error where b is the chamber bubble density. After the momentum of each track is known, a χ^2 fit of the event can be made for a given set of mass assignments, making use of the fact that in the chamber $b = c/\beta^2$ where β is the velocity of the particle and c is a constant which depends on the chamber operating conditions.

In order to obtain reliable results from this, within the theoretical limits, it is necessary to study the following questions : 1) Is the HPD spot sufficiently small, with well-defined edges, and with no halo? 2) Do the histogram pulses found by FILTER generally include all the hits on the track-slice, no more and no less? 3) Do the number of hits on a track depend on where it is situated on the photograph, for example due to film background? 4) What correction factor is needed for tracks or parts of tracks measured in the abnormal scan? 5) Do the final results depend strongly on the digitizing threshold level of the photomultiplier? (Any such effect is now minimized by automatic control of the level by the GATE program based on the number of hits on beam tracks.) 6) What is the best way of combining information from the three views?

It is rather difficult to separate out the data necessary to study any of these questions in isolation. For HPD 2 at CERN some of the studies are still being made in parallel with the measurement of the first experiment. However, the overall reliability of the bubble density information has been checked on a sample of 4-c fits. The results look very encouraging but cannot be published yet.

ROAD GUIDANCE SYSTEM PERFORMANCE

The performance of the road guidance system using HPD 1 attached to the CDC 6600 has been dealt with in previous papers(11. The first 2 m chamber/HPD 2 experiment consists of strange particle events produced by a 3.6 Gev/c anti-proton beam.

The main problems encountered in this experiment and the methods of solution were reported at a meeting in August 1967(12. The present status is that about 25000 events have been measured including about 8000 6-prong events which have also been used for ionization and other studies. However, only a small fraction has yet been through the full analysis chain. Present indications are, as already stated that the first-pass rejection rate is about 25 %.

The scanning and measuring rate at the Milady tables is about 5 - 10 events per hour, the density of events being one in seven frames. The time on HPD 2 for measuring an average event consisting of one normal and one abnormal scan has been found to be about 16 sec, as against a theoretical time of 12 sec. The theoretical time will not be decreased until the HPD is equipped with a new hydraulics system. The 16-sec time per event corresponds to a measurement rate of about 70 events per hour.

For various other reasons such as the frequent film changing necessary, difficulties with the film and temporary difficulties with the HPD and the GATE program, the actual average rate over longer periods is 30-35 events per hour. At Brookhaven a rate of 100 events per hour is maintained with the HPD attached on-line to an IBM 7094 computer. So there is room for improvement at CERN. Perhaps one lesson to be learnt is the usefulness of a CRT display with the GATE program for monitoring the performance. (At CERN a teletype is used for communication with the computer, and printers for display of road contents and fiducial boxes)

MINIMUM GUIDANCE

The HPD offers the theoretical possibility of automatically recognizing events as well as measuring them; in fact attempts have been made and are still being made to do this at other laboratories. At CERN, however, it was considered that with the film quality seen up to now and given the still limited computer capacity available, this is not yet a practical economic proposition.

A project was begun with the limited objective (at least initially) of finding and measuring the tracks of an event given only a Milady measurement of the vertex on each view and an indication of the number of tracks at the vertex. This system is called "minimum guidance" and was started in June 1966, in collaboration with RHEL. Progress with the system and results from trials on three experiments were reported in August 1967[14] [15].

As can be seen from Fig. 5b the program chain is very similar to the read guidance chain. MGGATE finds and checks the picture number as usual, but instead of gating roads, merely outputs the whole of the useful part of the picture in packed form. The W's are packed four per 60-bit CDC 6600 word, and there are two separate arrays (a) for stage coordinates (X's or Y's) and (b) for pointers to the beginning of each scan-line in the W-array. The MGFILT program thus has semi-random access to the whole picture.

It is impossible to describe the MGFILT program in a few words. However, one basic technique used for finding tracks should be mentioned, namely stringing[13], as it has a bearing on what data reduction may be done in MGGATE. Stringing means associating together, in clumps of not more then eight, digitizings which are close enough together to be nearly certain of belonging to a small piece of track, fiducial or scratch. (The analogy in the case of the FSD spark chamber programs is finding groups of digitizings belonging to sparks and replacing them by their centroids). The effect of stringing a part of a picture can be seen in Fig. 6; points belonging to the same string are marked by the same letter or figure locally. Techniques based on stringing are used in conjunction with histogramming in MGFILT. Track following is another basic technique.

Some general principles were observed when writing the MGFILT program, partly because it was a collaboration project:

(1) Until the techniques were found to work, it was written entirely in Fortran, except for the routine which gates one scan-lines. (2) It was written in modular fashion, in the form of routines to perform basic functions, the overall strategy and flow-chart being decided later. (3) Adequate facilities for testing, including printer plots, were built in. (4) The number of parameters which have to be adjusted for different experiments was kept to a minimum. (5) The program has been documented as it was written, and any modifications to any routine noted immediately. The amount of data which has to be transmitted from the MGGATE program is fairly large - about four times that of the road guidance system. Assuming 24,000 60-bit words per event-view, then 150 event-views can be stored on 1" magnetic tape. At 100 events per hour this means a change of tape every half-hour, or about every 20 minutes with half-inch tape at 800 b.p.i. It is not believed to be feasible to achieve any major reduction without in effect combining MGGATE and MGFILT. One possibility which could reduce the amount of data by about one third would be to find strings in the on-line phase. This would in any case be desirable in order to estimate the number of hits on beam tracks, for control of the digitizing level in the MGGATE program.

At present the minimum guidance system is being set up to measure an 81 cm chamber experiment using HPD 1. The experiment consists of four-prong events from a 750 Mev/c anti-proton beam. The complete chain of programs required for production measurement works but requires improvement here and there. Tests indicate that events can be measured on the Milady tables at a rate of about 30 per hour.

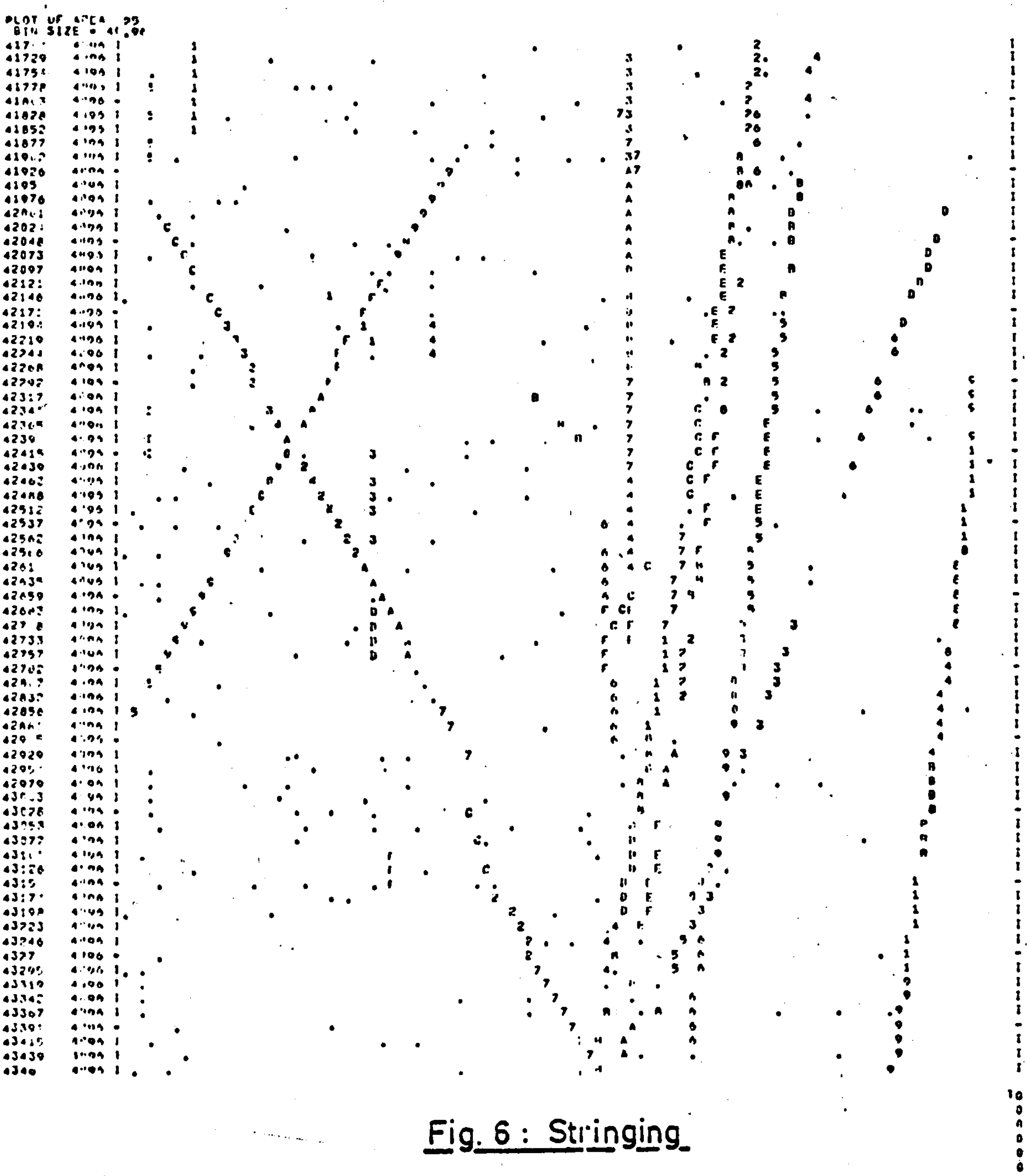

Fig. 6 : Stringing

Out of a sample of 101 events without noticeable scan-table error, 62 were reconstructed and fitted in the kinematics program successfully. Furthermore, in all but two or three events out of the remainder, MGFILT outputs sufficient information for successful reconstruction, if only the track-match and geometry program were clever enough to recognize it. This has been proved by making a manual selection of corresponding track images from those output by MGFILT. In some cases there are extra track images, for example from a passing beam track, and in other cases, a single track-view is missing. This selection is made with the aid of the plots of the average points found by MGFILT. An example of such plots is shown in Fig. 7; in this case, there are extra tracks on views 1 and 3 and the beam track is missing on view 3. Attention is now being concentrated on improvements to track-matching as offering the best hope of improving the performance of the minimum guidance system.

To conclude on minimum guidance, the results from the first 100 events seem extremely encouraging; it is hoped that the next sample will not show a deterioration, but this is by no means certain yet. If it is necessary to call in human judgment to help the computer, it is hoped that this can be at the level of track-match where the quantity of data to be kept and displayed by the computer is very much less than at the MGFILT stage.

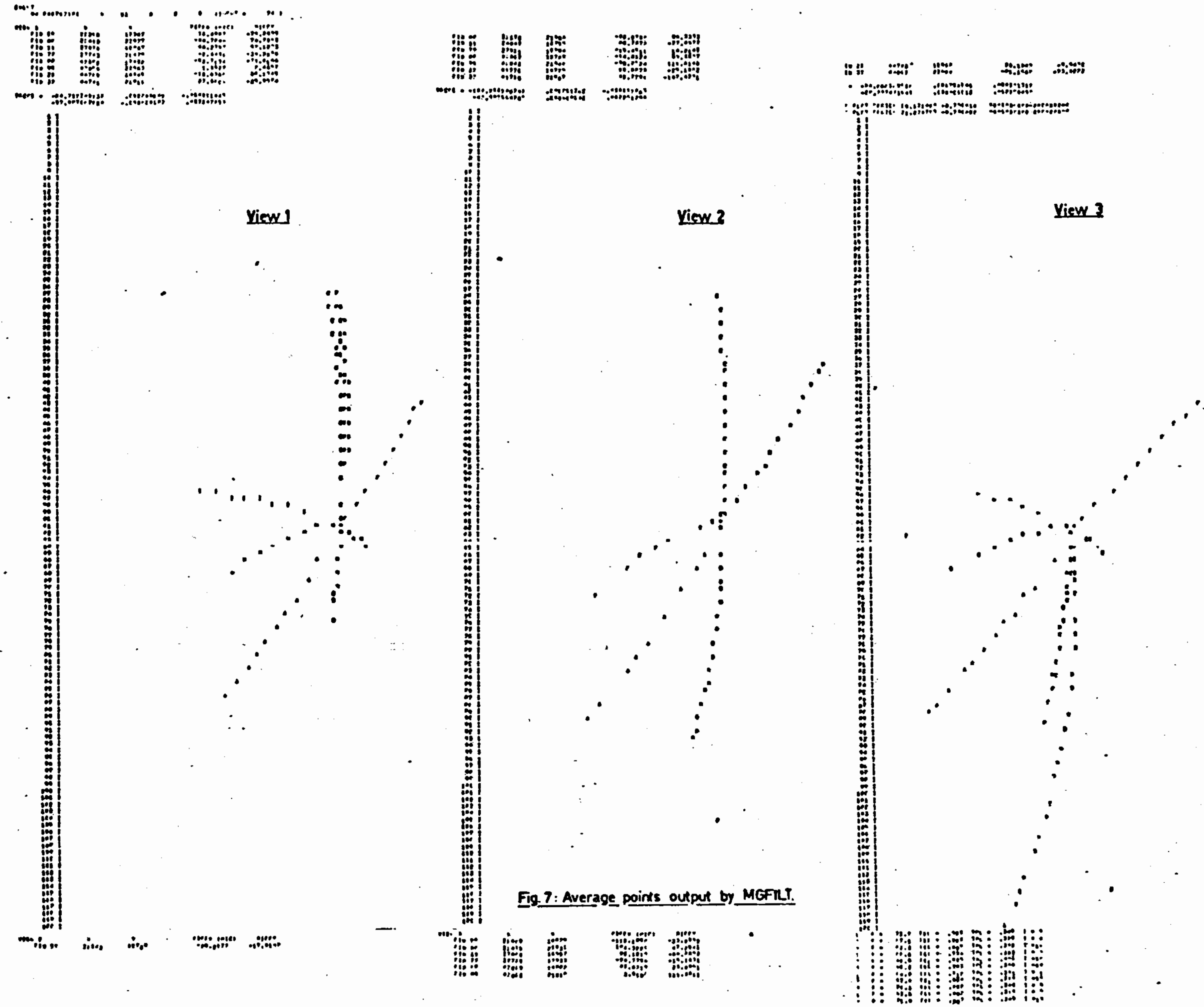

Fig. 7: Average points output by MGFILT.

CONCLUSIONS

At CERN, two 80 cm Bubble Chamber experiments have been measured using HPD 1, and at present a 2 m chamber experiment is being measured using HPD 2 on-line to the CDC 6600 using the road-guidance system. The program system has had to be modified somewhat both for HPD 2 and for some problems encountered for the first time in this 2 m chamber experiment. Checks on the measurements of all the experiments have shown the precision to be better than that of the manual devices (IEP). Bubble density information is now being really used for the first time and is believed to be satisfactory.

The average rate of measurement on the HPD is at present about half the peak rate of 70 events per hour, which in turn is less then the 100-per-hour theoretical rate. The average rate is continually being improved, and the back-log of events measured on the Milady tables being reduced. For the moment, measurement on the Milady tables is not a bottleneck. To be ready for the day when it is, the minimum guidance system is being developed.

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