школа ЭВМ г.Алушта

ЭВМ

В ЭКСПЕРИМЕНТАЛЬНОЙ ФИЗИКЕ

1968 г.

ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

ЛАБОРАТОРИЯ ВЫЧИСЛИТЕЛЬНОЙ ТЕХНИКИ И АВТОМАТИЗАЦИИ

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DATA PROCESSING FOR FILM AND FILMLESS SPARK CHAMBER EXPERIMENTS

Лекция, прочитанная в Школе ОИЯИ по применению электронных вычислительных машин в задачах экспериментальной физики

г. Алушта, Крым, СССР, 5-19 мая 1968г.

* CERN

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".

Ректор Школы

доктор технических наук

Г.ЗАБИЯКИН

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

1. INTRODUCTION

It is intended in these talks to deal with the use of computers in the evaluation of spark chamber experiments. Two aspects are particularly emphasized, namely the automatic scanning of film and the processing of experiments on-line to computers.

Most of the techniques which are described in this paper have been developed at CERN, though some methods contributed by other laboratories are also mentioned.

The time scale involved in these developments covers the last five or six years. During this period a rapid expansion of the use of computers has occurred. The availability of modern digital computer systems with flexible input-output and microsecond logic and arithmetic has stimulated a variety of applications in the high-energy physics laboratories. One of the most interesting results is the high degree of automation achieved in the analysis of both film and filmless spark chamber data. This topic will now be illustrated starting with a recapitulation of the basic features of spark chambers.

1.1 Spark Chambers

The Spark chamber is now a classic experimental tool in high energy physics. It is used to detect the passage of charged particles and to give accurate spatial information about their trajectories. This spark chamber detector relies on the presence of ions along the particle's path and involves a gas discharge in a gap between two parallel plate electrodes.

The main characteristics are :

i) sensitivity time of a few microseconds

ii) dead time between successive events of a few milliseconds

iii) possibility of triggering the detector

These features combined together make the spark chamber an ideal device for collecting very large statistics of selected and reasonably clean events. To give an idea of the scale of operation involved, spark chamber experiments normally record of the order of $10^5 - 10^6$ events. This vast amount of information clearly poses serious problems of data handling and calls for a high degree of automation. Fig. 1a is a schematic diagram of a parallel plate spark chamber and Fig. 1b gives an example of the use of spark chambers, showing the beam layout of an elastic scattering experiment.

How are the spark positions read out? The first spark chamber used in experiments recorded spark positions by optical methods. Stereoscopic photography was adopted making use of the experience gained with bubble chambers. Fig. 2a shows how 90° stereo-views of the chambers may be obtained and Fig. 2b shows the resulting picture layout. The pictures were initially measured on standard manually operated digitized projectors. The measurements were recorded on cards or punched paper tape and provided the input data to a typical chain of analysis programs performing geometrical reconstruction and kinematical analysis of events and statistical evaluation of experiments. Because the slow manual measurement was a serious bottleneck, various fully automatic scanning and measuring systems were developed in several laboratories[1]. In addition to the already existing HPD flying spot digitizers[2], a variety of film measuring devices specifically designed for spark chamber pictures were constructed. Automatic analysis of photographic information was first reported on in the years 1963-64[3,4,5].

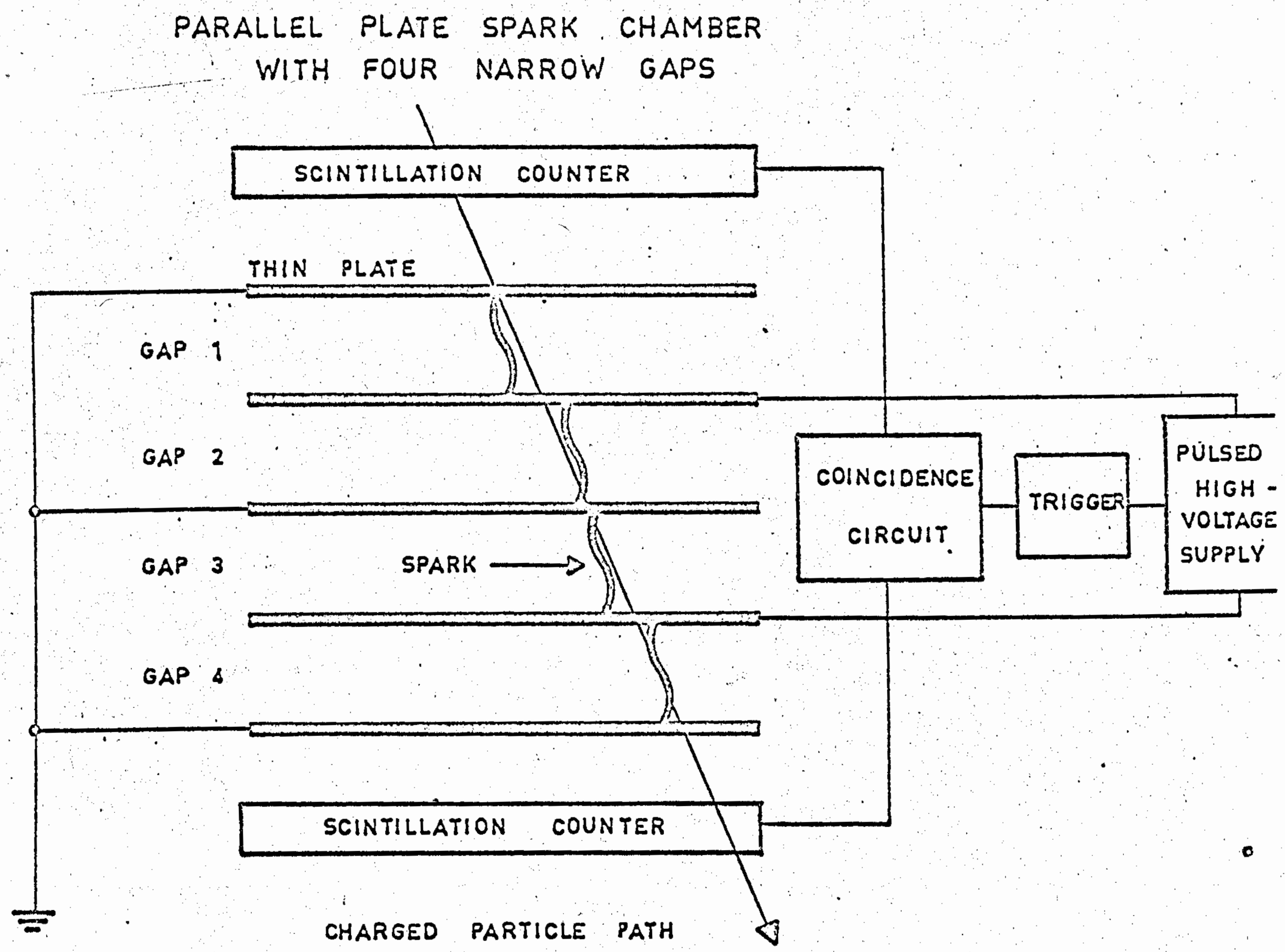

FIG. 1 a

SCHEMATIC DIAGRAM OF A MULTI – ELECTRODE SPARK CHAMBER

SCHEMATIC DIAGRAM OF THE $\pi^{\pm}-p$ / $p-p$ ELASTIC SCATTERING EXPERIMENT AT 8, 12, AND 18 GEV/c

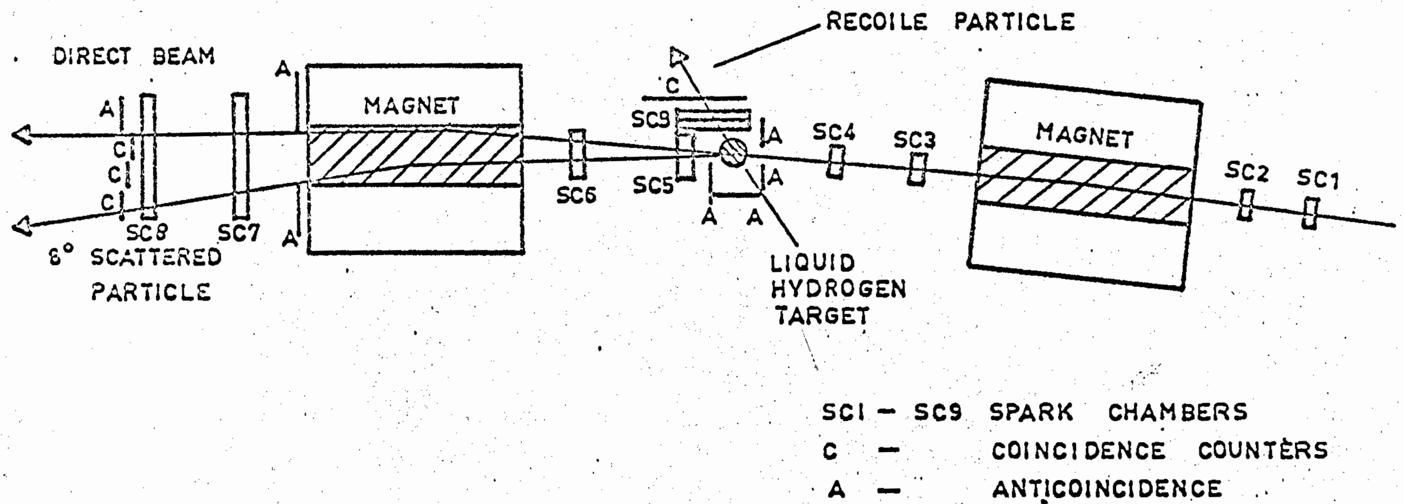

FIG. 1 b

BEAM LAYOUT FOR A SPARK CHAMBER EXPERIMENT

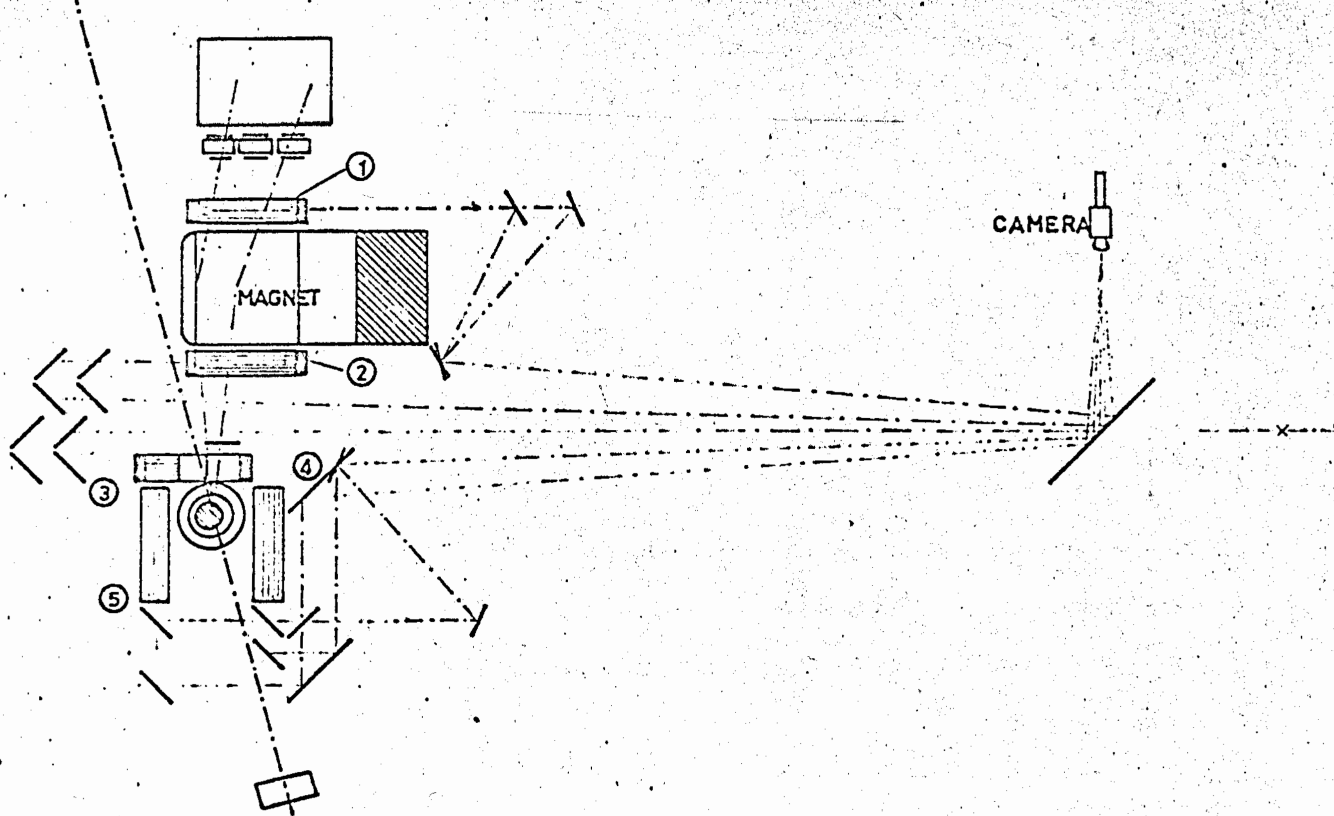

FIG. 2 a

EXAMPLE OF PHOTOGRAPHIC READ-OUT

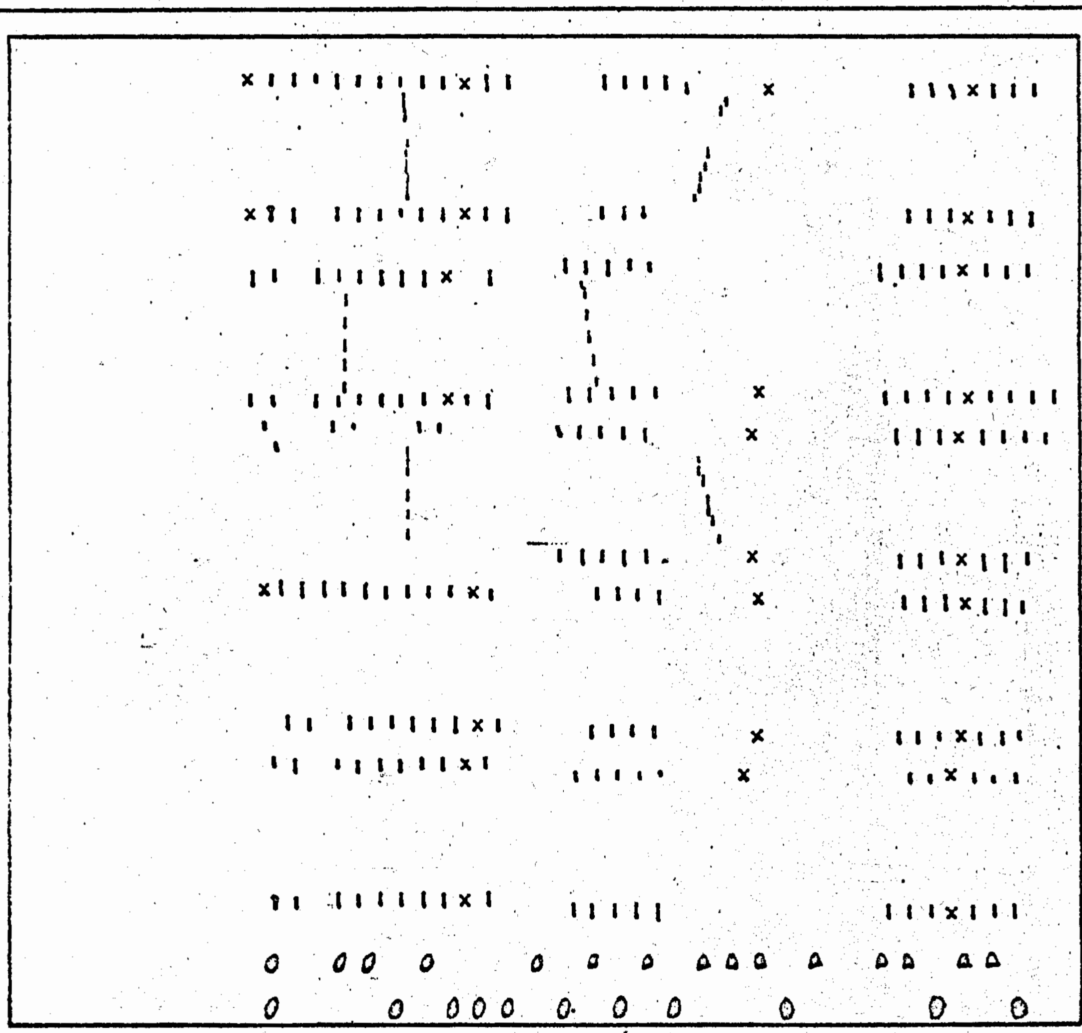

FIG. 2 b.

EXAMPLE OF PICTURE FORMAT

In recent years a number of filmless digital read-out techniques have been successfully tried out. (vidicon systems, acoustic chamber, wire chamber etc). They offer two marked advantages, firstly that of removing the slow camera and hence allowing the chambers to be operated at higher speed, and secondly that of producing digital output thus enabling direct transmission into an on-line computer.

The wire chamber is by far the most important of the filmless spark chambers. It has been used in many experiments, it can be pulsed at frequences compatible with its dead time and it works satisfactorily with two or more sparks per gap. It is similar to the optical chamber except for the method of reading out the spark coordinates. Instead of plane sheets of aluminum foil the electrodes consist of planar arrays of parallel conductor wires placed at a distance of about one millimeter from each other. The discharge current follows the wiros hit by the sparks in each plane thus enabling one to locate the sparks positions.

Fig. 3a shows a diagram of a wire chamber. Figs. 3a and 3b illustrate the two commonly used methods of reading out the spark coordinates, namely magnetic core and magnetostrictive read-out systems.

The parallel plate optical chamber and the wire chamber are used for the major part of the experimental work at present. In what follows the data handling aspects of these two types of spark chamber only will be considered.

1.2 Data Handling

Many data handling problems are common to film and filmless spark chambers. In both cases one has ultimately to analyse spark measurements.

WIRE CHAMBER

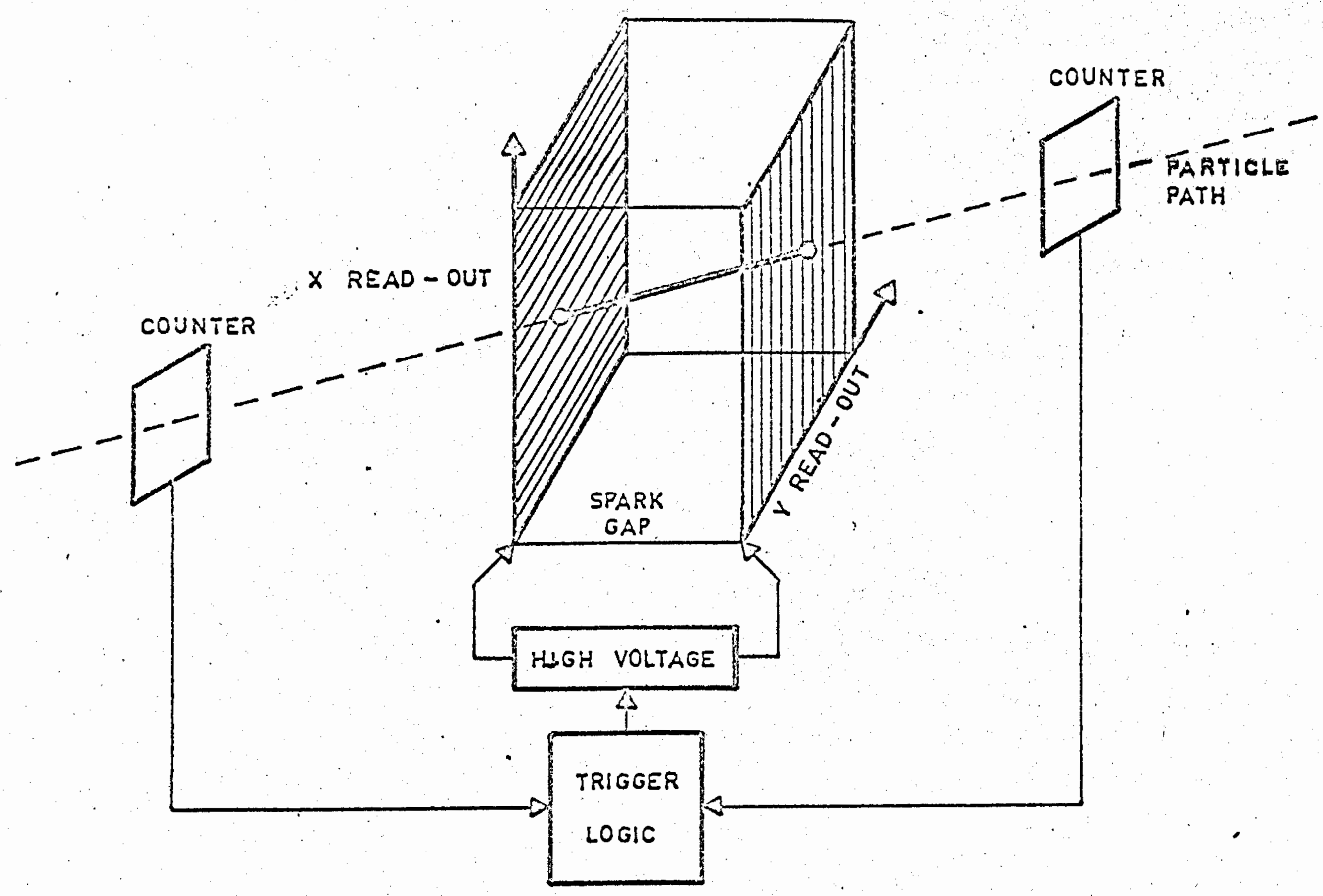

FIG. 3a

MAGNETIC CORE WIRE PLANE READ-OUT

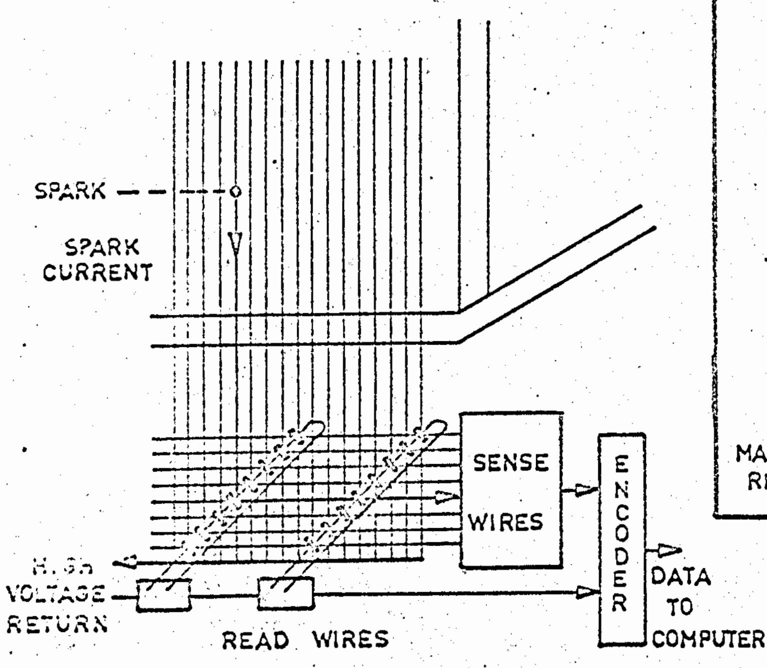

FIG. 3b

MAGNETOSTRICTIVE WIRE PLAN READ-OUT

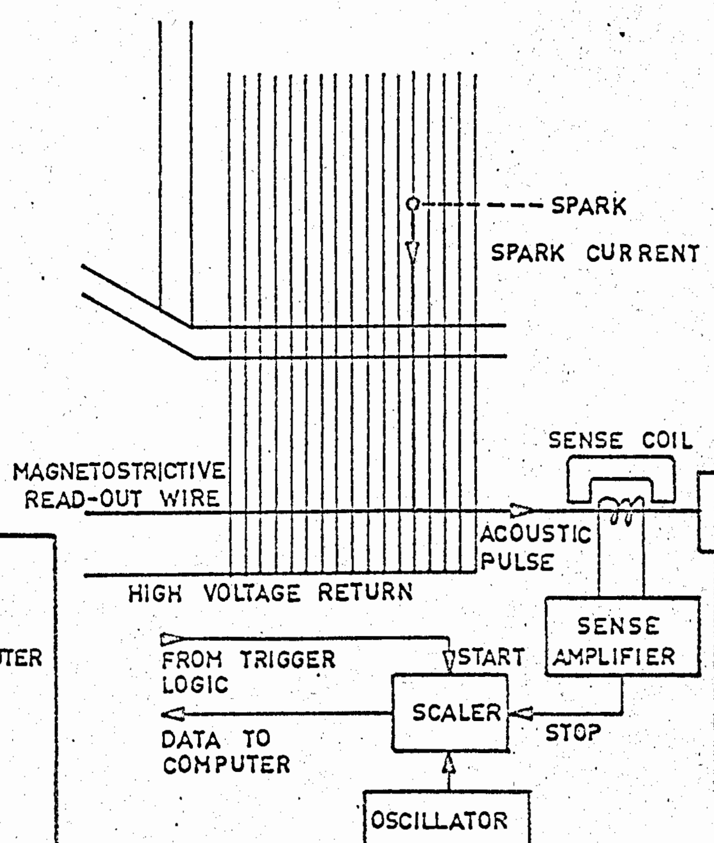

FIG. 3c

The main tasks of the automatic data-handling system may be listed under three broad headings, as follows :

<u>Stage 1</u> : Data acquisition and reduction

<u>Stage 2</u> : Event recognition and classification

<u>Stage 3</u> : Geometrical and kinematical analysis of the events.

Stage 1 involves the acquisition of digital information by the computer from the measuring device (coordinates) or from the wire chambers (wire numbers). It also involves, by means of computer programs, the reduction of this information into strictly essential data, i.e. the coordinates of spark centroids.

Stage 2 involves the recognition of particle tracks in each chamber, the identification of the triggering event and its classification according to the programmed scanning criteria.

Stage 3 includes the geometrical reconstruction and kinematical analysis of the interesting events and the statistical evaluation of the experimental data.

Stage 2 and 3 are both carried out in much the same way for optical or wire chambers. In some cases one can actually use the same program, as we actually have done.

Concerning stage 1, it may be stated that, if wire chambers replace the film scanner, the structure of the on-line computer system is not changed very much. In both cases there are very similar problems of equipment control, data acquisition and storage, man-machine communication, log-keeping etc. The data input rates are also comparable.

However, while in the case of film some pattern recognition is required to interprete the data box information (picture number, roll number, supplementory data concerning the event), to reconstruct the fiducial centres and to recognize the sparks, in the case of wire chambers this data is readily available.

The automatic analysis of spark chamber pictures will now be described, followed by an outline of the methods used in the evaluation of wire chamber experiments. The emphasis will be on the techniques used in the first and second stages of data handling.

2. EXPERIMENTS USING FILM

One of the appealing features of spark chamber pictures is that the information content is small relative to bubble chamber photographs. The trajectories of the particles participating in the selected reaction are seen in the presence of a minimum amount of background. Another important feature is that the spark images which delineate the particle tracks are confined in the gap regions which are normally arranged in the picture in a known, regular geometrical fashion. It is certainly because of these characteristics that automation has been achieved in a rather short time.

However, a well planned automatic system has to take into account the particular way spark chambers are used. In fact, since these detectors are relatively inexpensive and easy to build, their use is generally limited to one or a few experiments. Unlike bubble chambers, spark chamber flexibility permits radical changes in picture format to occur from experiment to experiment.

Firstly, the arrangement of the chambers can vary considerably at the experimental area, so the chamber images may be disposed quite differently on the pictures of different experiments. Secondly, the number and the dimensions of the chambers, the sizes and positions of the gaps and electrodes, the film format etc. represent possible degrees of freedom. Thirdly, the scanning criteria are experiment dependent as are the topological characteristics of the events.

Because of this variety of possible picture structures a high degree of flexibility is required in the automatic scanning systems, in order to accommodate different experiments.

Figures 4, 5 and 6 are examples of pictures taken from three different spark chamber experiments performed and automatically analysed at CERN.

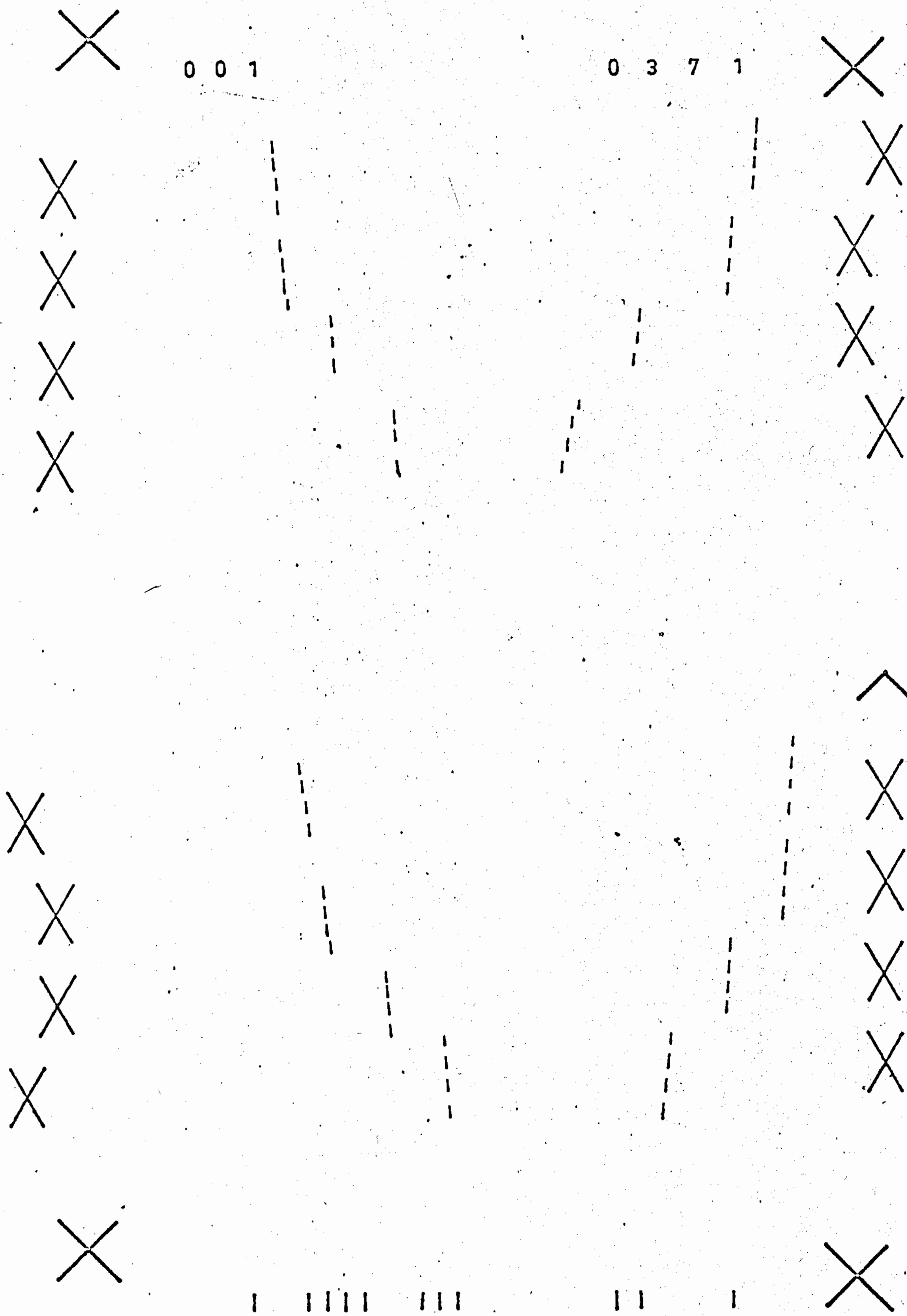

FIG. 4
EXAMPLE OF SIMPLE TOPOLOGY EVENT

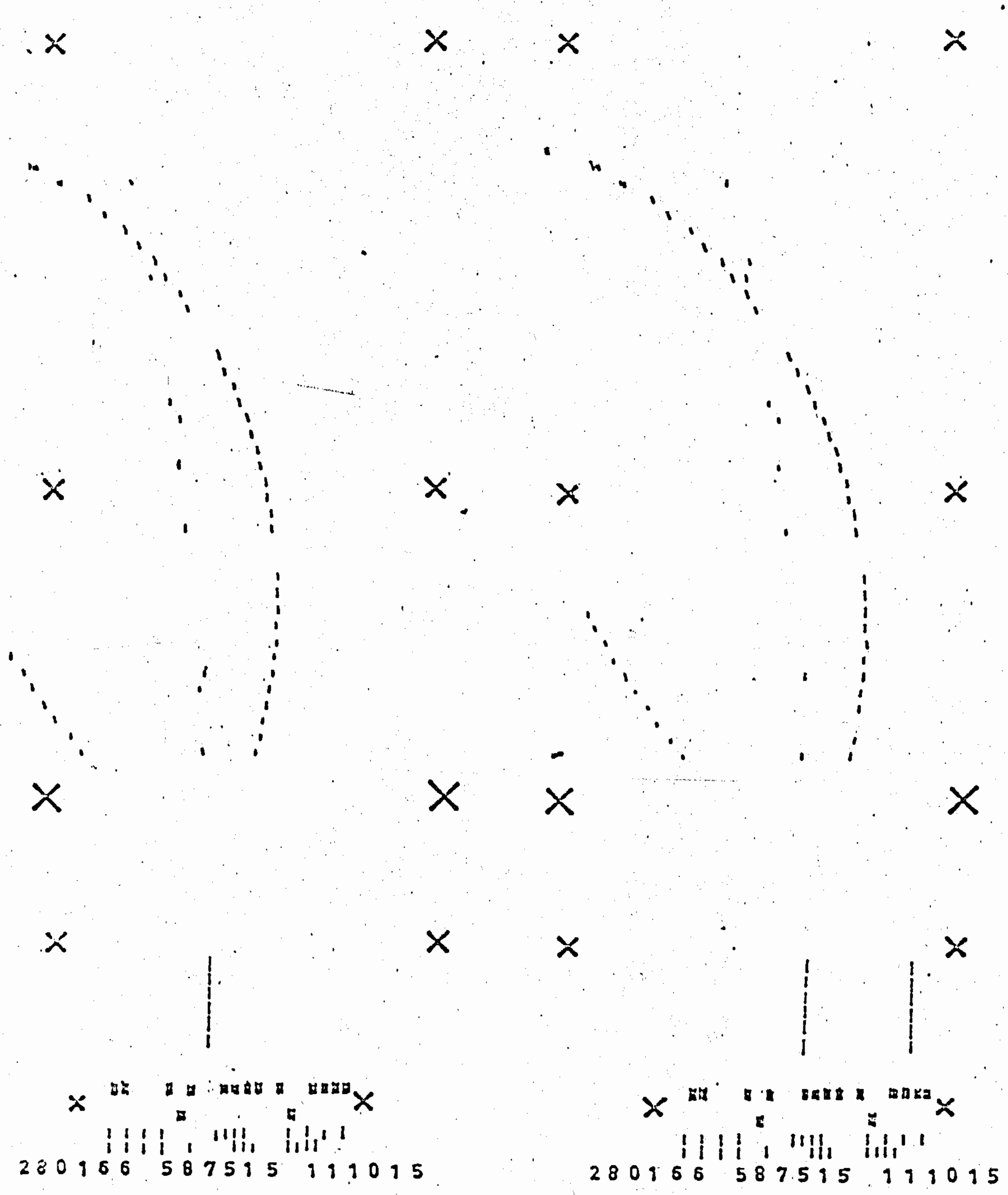

FIG. 5

TYPICAL FRAME FROM AN ETA – DECAY EXPERIMENT MEASURED BY THE CERN HPD

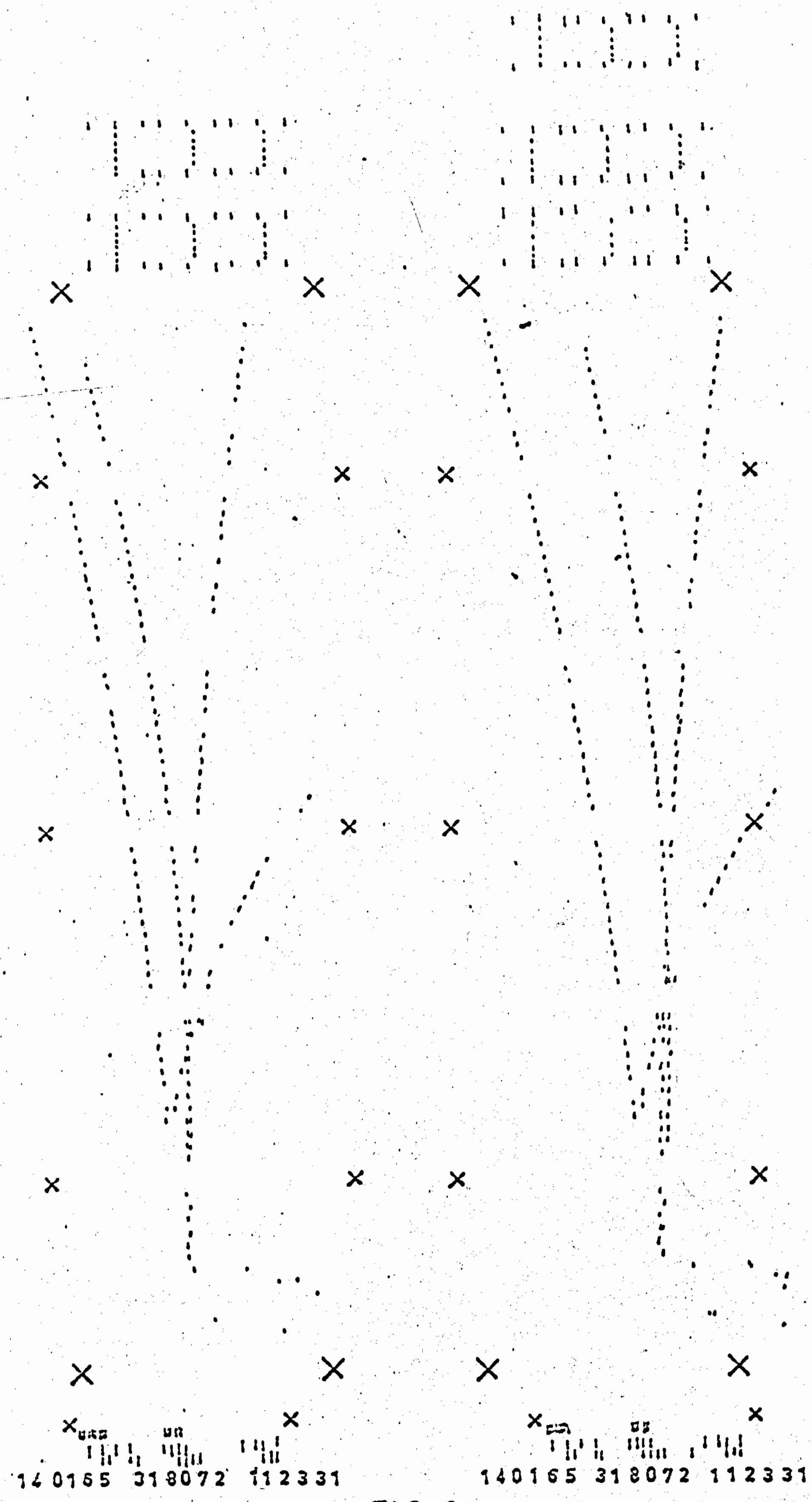

FIG. 6

NEUTRAL V's IN A LARGE MAGNET DETECTED BY A SPARK CHAMBER SYSTEM

2.1 Automatic Film Measuring Devices

Many types of automatic film measuring device have been developed in various European and American laboratories. However, their basic working principles are rather similar and may be described in a general way.

The element of film to be measured, is examined by a small circular spot of light which is obtained either mechanically (HPD) or electronically (CRT scanners). When the bundle of light rays generating this spot traverse a black or white image (for example a spark), the change in the intensity of the transmitted light is detected by a photomultiplier placed behind the film. The electronic circuits of the scanner then record and output the appropriate measurements of the detected image (e.g. coordinate of the centre, width, light intensity).

The scanner is connected on-line to a computer, so that the measurements are transmitted either directly or via a small intermediate buffer to the computer memory where they receive a first stage processing simultaneously with the measuring process. Also by this connection the measuring device is placed under the control of the computer program. This means that its operation is flexibly programmed and its performance is continuously checked.

What commands can the computer send to the scanner ? All the scanners at present used are capable of executing basic orders such as : advance or backspace the film by a given number of frames, initiate or terminate measurement, etc.

But the degree of programmability of the measuring process itself is the main parameter which differentiates the various types of scanner. At one extreme the system developed at MIT by Prof. Deutsch 3) has a maximum degree of programmability. The spot is sent to an address (x,y) on the CRT surface by a computer command

and the device simply tells the computer whether at that point the film is dark or clear. On the basis of each single answer, the program decides which point to interrogate next.

At the other extreme the flying spot digitisers (FSD's) such as the HPD system have a minimum degree of programmability, and therefore maximum independence from the computer. One command causes the complete measurement of a specified picture, in the manner of a TV raster scan. The FSD samples the whole frame by parallel lines continuously transmitting the digital information. It thus builds up automatically in the core memory of the computer a digital image of the measured picture.

Between these two extremes, one finds automatic film scanners with various amounts of built-in programmability and HPD-like autonomy.

To conclude the discussion of the philosophy of the "scanner-computer system", it is worth emphasizing that the main difference lies in the extent that the film is used as a random access memory. The logic of the data processing programs is remarkably similar in the various cases. Since, at CERN we adopted the raster scan technique, the concrete examples given in the following sections will be mainly related to this method, without in any way affecting generality.

Finally, the measurement time depends on the film format, picture content and type of scanning device. For programmed spot instruments one can define a characteristic "point interrogation" time, which is typically several microseconds. For flying spot digitisers one can define a "scan line" time which is typically of the order of a millisecond. The total number of point interrogations or scan lines depends on the amount and distribution of the data in the picture. Typical measurement times are in the range 1-15 seconds/picture.

Today, one knows how to design, construct and operate automatic film measuring machines. Many such devices exist and are currently being used for a wide variety of experiments.

2.2 Organisation of Programs

Experience has shown that the successful construction of a film measuring machine solves only part of the film measurement problem. Contrary to early expectations, at least as much effort is needed to make the computer system with its various program stages work properly.

The computer has to be programmed to carry out a wide variety of functions. Besides the automatic recognition of the events, which is in itself a major job, there are many other technical problems to be solved before smooth production of results can start. Problems arise, for example, in the design of the interfaces with special equipment and with the operator, in the proper accounting of large quantities of data and there are timing and data rate problems in input and output.

The program must also include a large number of checks for hardware and operator errors in order to avoid unnecessary stoppages. Some fault conditions, such as those caused by strips of poor quality film or by operator errors during film and tape handling can easily be foreseen. Others, such as I/O channel and magnetic tape errors are not so easy to predict but the program must be able to deal with them all. When everything works properly, one realises that an important fraction of the code has been written in order to maintain continuously efficient operation.

Whilst they are being developed, the programs need to be continuously updated. The number of trivial programming errors made during this phase is minimised if the interface between the computer and the programmer is simplified as much as possible. For this reason, programs are generally written in FORTRAN-like high level languages.

It is also convenient to break large programs up into logical blocks and subroutines, each performing a well defined function and with an overall structure which can be used for several programs each analysing a different experiment. Then modifications during development are easier to make and the amount of re-programming needed for the analysis of a new experiment is kept to a minimum. This overall structure is achieved by carefully separating the experiment dependent, computer dependent and measuring device dependent sections of the program, by generalising the most commonly used routines to cover a wide variety of applications and by gradually building up suitable program libraries which contain the most useful version of each subroutine.

The detailed design of the sofware for an automatic scanning system depends of course on the type of film scanner available, on the computer to be used and on its operating system.

How much of the data processing has to be done in real time ? Ideally, one would like to carry out as much as possible of the three stages of computation in parallel with the measurement so that any feedback is available immediately and the picture may be re-examined if necessary. Unfortunately, this would require a large, powerful and therefore expensive computer, or alternatively would slow the measurement rate down considerably. The most realistic aim is to do only as much analysis on-line as is necessary. We would regard the completion of Stage 1 defined above as an absolute minimum. Experience at CERN has shown that anything less than this leads to inefficient running of the system both because of insufficient control of the measuring instrument and insufficient reduction of the digitised data.

The execution of Stage 1 programs in real time guarantees some control over the measuring device and therefore minimises the need for re-measurements. For example, a variety of checks can be applied to fiducial marks, data box and spark information. Also, a reduction of the data by an approximate factor of ten is normally achieved by saving only the coordinates of the spark and fiducial centres; most of the background digitisings are eliminated and tape handling operations are simplified. Storing the output from Stage 1 is also a useful safety precaution even if further calculations are carried out on-line. This output contains all the essential data which would have been collected by manual measurement of the picture and represents an unbiassed description of the event in digital form with a minimum of redundant information. If an error is found in the programs used for later stages of the analysis or if these programs are subsequently improved, the experiment can be reprocessed without remeasuring the film.

What computer configuration is required to perform the Stage 1 tasks ? Among the many possibilities offered by modern computer systems, let us consider two; either a machine matched to the requirements of the assignment or the use of part of the capacity of a large multi-programmed computer system. At present, economic considerations seem to be in favour of the first solution. Looking ahead, however, one can imagine large systems in which current difficulties (which involve the balance between input/output and central processor speeds, access during development of hardware and software, capacity of the various types of storage, real-time response, economy etc.) have been overcome so that the second solution may be more attractive.

To match the requirements of the film scanner the computer should have enough core memory to contain Stage 1 programs and digitisings. Programmable spot digitisers require memory sizes in the range 8-16 K words (K=1024) of 16-24 bits. Flying spot digitisers require relatively more memory because they store the whole picture. We would consider 16 K adequate for many applications, but rather on the low side for complicated pictures.

The computer should have a sufficiently powerful central processing unit to perform all the required calculations without slowing down the digitiser. There must be fast buffered input/output channels to ensure the transmission of digitisings from the scanner directly to the computer memory and from the memory to magnetic tapes or disks, without stopping the central processing activities. For the man-machine interactions the availability of display equipment such as teletype, line printer, CRT's, is of the greatest importance. An interrupt system makes the transmission of data easier and quite independent from the central processor attention. A backing store of reasonable capacity, allowing for storage of program overlays, containing for example diagnostic routines for the measuring device, calibration programs etc. is also essential for smooth running of the system.

2.3 Processing the output from a flying spot digitiser

When starting to process the digitisings from a scan, the computer program has first to identify the frame and it does this by searching for the digitisings corresponding to the roll and frame numbers in the data box. All the numbers in the data box, which may include such supplementary physics information about the event as the type of particle which initiated the event, the triggering conditions, etc. are coded in binary form and appear on the photograph as a series of strokes which are long enough to be traversed several times by the flying spot.

The next step in the analysis of the picture is the search for fiducial marks. Efficient programs exist for the recognition of X-shaped marks and are commonly used both for spark and bubble chamber pictures. These techniques are based either on global histogram methods or on local search for nearest-neighbour digitisings. When the points which belong to each arm are collected, lines are fitted to them by least squares and the coordinates of their intersection are obtained. Once two or three fiducials are found the program can define search areas on the film where spark gaps and other fiducial marks are located.

In doing so, one assumes that the relative position of chamber images and crosses is known and constant. Therefore every spark chamber should have its own fiducial marks (two or more) rigidly connected to it and seen by the camera through the same optical path as the sparks associated with each view.

Digitisings inside each gap are then examined by the program in order to find sparks. A spark is defined by the presence of two or more digitisings which lie on successive scan lines, and whose coordinates in the scan direction are separated by no more than one spark width. When sparks are recognised, the coordinates of the points on each spark are averaged and the average coordinate is stored. All the points lying within the gaps but not associated into sparks, as well as all those lying outside the gap search regions are ignored by the program and regarded as noise digitisings.

The reduced data is packed and stored on magnetic tape, but before doing this it may be necessary to apply some corrections to the spark coordinates. Firstly, the film measuring device may be one of those relying on dynamic calibration techniques to correct for drifts and non linearities in the scanning raster. For example, the Luciole[6] CRT scanner at CERN requires a regular calibration every two hours or so. In this a grid of straight lines crossing at 45° is scanned by the flying spot and a program finds the coordinates of the intersections in the Luciole reference system. These coordinates are then compared with accurate microscope measurements of the grid points and a correction map is set up in the computer. Then after the measurement of any frame, all the spark measurements have to be corrected by an amount which is found by interpolating between the four nearest grid points.

Secondly, some corrections might be necessary due to the mode of operation of the spark chambers themselves. Often, the centroid of a spark is not the best point to give as a measurement. In fact, the combined effects of clearing fields and slow rise times of the pulsed voltage may amplify the scatter of spark centres from an inclined particle trajectory. It is possible to correct for these effects by measuring the spark at a convenient plane in the gap rather than in the middle. This plane where the various electromagnetic effects almost cancel, can be empirically or theoretically calculated for each spark chamber. If the spark chamber is in a magnetic field, one has also to correct for systematic displacements of sparks caused by the combined effect of the magnetic and electric fields on the ionised gas.

It has been observed that the statistical distribution of spark distances from particle trajectories has an r.m.s. of 0.18 mm along the gaps when all the biases have been removed and only the effect of drifts of the primary and secondary electrons produced in the ionisation process are included. When a very accurate flying spot digitiser, such as an HPD, is used in connection with good quality film, such as that shown in Fig. 5 (space-film demagnification of ~ 25) one may obtain a comparable figure (0.20 mm) for the r.m.s. scatter of sparks around the reconstructed trajectory in real space.

2.4 Pattern Recognition

This data handling stage is concerned with the pattern recognition of the events from amongst all the spark measurements supplied by Stage 1. Unlike the scanning girl, who takes measurements in an orderly fashion along the particle tracks, carefully avoiding all kinds of background and thus performing during the measurement the recognition of the event, Stage 1 programs systematically measure all the sparks gap by gap. They arrange them simply in a left to right order, separately for each gap, without attempting any correlation between gaps of the same view (track recognition), between views of the same chamber (track matching) or between chambers of the same picture (event recognition).

The pattern recognition programs have first to concentrate on each spark chamber view separately and select the sparks which belong to the same track. This selection may be complicated by spurious or missing sparks, crossing tracks etc. When this operation is completed, the computer memory contains arrays of sparks ordered according to the various track images within each view. Background sparks have been eliminated and the total amount of data is therefore further reduced.

Another ordering operation is then necessary, to select corresponding tracks in the two stereo-views. This is particularly difficult when 90° stereoscopy is used. In fact, in this case all combinations lead to geometrically acceptable solutions. The scanning girl is trained to base her choice on a variety of criteria some of which depend on information available on film but not necessarily available after the digitizer operation, for example spark width, intensity, shape etc. One of the solutions is suggested by the occasional inefficiency of spark chambers. On any track, one or more sparks may be missing and therefore one can check that corresponding sparks are either present or absent in both views of the same track. Another method consists of causing, by means of a prism, a displacement of all the spark images in one gap. On the picture they appear to be off the track by a distance proportional to the spark depth in the chamber as seen in that view. This may help the track matching in cases where the first method proves inadequate.

During this recognition phase, background tracks which have been simulated by film scratches or made up by spurious sparks are removed. So, we are ending up with ordered sets of sparks, much the same as those which would have been obtained by measuring the picture by hand except for one more correlation step.

To complete the pattern recognition we still have to associate these tracks into a consistent event. This is done by looking for trajectories which continue from chamber to chamber and by finally retaining only those tracks which are essential to the description of the interesting event.

The event selection or scanning criteria are applied throughout Stage 2 programs as soon as the necessary data are available. If an event passes all the tests, it is labelled "good" and the ordered co-ordinates of the sparks are stored on magnetic tape. The measurements are still related to the digitizer coordinate system. They form the input to Stage 3 programs which carry out the geometrical reconstruction in space and subsequently the calculation of the various kinematic quantities.

If the event fails to pass a scanning test it is immediately rejected and a coded reason for the rejection is given. All this information is accumulated by the accounting sub-program which at the end of each roll of film prints out a summary of the automatic scanning performance including the distribution of the pictures into the various event classes.

This distribution can be compared with what is expected and may therefore represent another useful control over the performance of the data processing system.

After having discussed what pattern recognition programs have to do, it will now be shown how they do it.

2.4.1 Linear Tracks

Methods for linear track recognition may be divided into two categories : those using local search techniques (track following) and those based on global approaches. Track following methods usually involve starting looking for sparks at one end of the chamber and associating them into tracks by criteria of closeness while progressing towards the opposite end of the chamber. Global methods make use of all the sparks simultaneously and in our experience give better results because they are generally less sensitive to missing hits and background sparks lying near the tracks. One method of this type will now be described.

Let us indicate by Y (i,j) the general element of the available spark array. It represents the Y-coordinate (i.e. the coordinate in the direction parallel to the plates) of the j-th spark of the i-th gap (i = 1,2 ...: n is the gap number in an n-gap chamber).

The purpose of the method is to rearrange these data into an array containing the spark measurements of the recognized tracks, Y_t (i,k), (coordinate of the spark in the i-th gap which belongs to the k-th track).

A track is defined as a set of sparks which all lie within a road of width 2d centred on a straight line through two sparks of the set. No two sparks must come from the same gap and the set must contain a minimum number, t, of sparks ($2 \leq t \leq n$). The slope of the base line must be between two given limits, s_1 and s_2. The two sparks defining the road may be any pair from the set which allow the above conditions to be fulfilled. The parameters t, d, s_1 and s_2 are generally different from chamber to chamber. They are transmitted to the track searching routine as part of the calling sequence and tell it the threshold conditions to be satisfied by physically possible and acceptable tracks.

The track searching routine selects two gaps such that their spark content be minimum and the distance between them be maximum. It then constructs the lines connecting the sparks of one gap to those of the other in all possible ways. Each line whose slope s is included in the range $s_1 \leq s \leq s_2$ is chosen to become the axis of a road of width 2d traversing the chamber. The number of sparks inside each road is counted in turn and if it is greater than or equal to t, the track is accepted. When a track is accepted the spark coordinates are moved (and erased) from the Y to the Y_t matrix. If no candidate fulfils the conditions imposed on a track new pairs of gaps are tried out. The iterative procedure converges because sparks are removed from the original array either because they belong to a track or because they are regarded as background having failed to form tracks in a sufficient number of trials. After a few iterations the number of non-zero elements in Y falls below any workable amount and the procedure is terminated.

This algorithm has been programmed and used as a general subroutine in a wide variety of cases. A few variations are used in special situations. For example, in some cases it may be difficult to fix a value for t which ensures efficient recognition. This value is normally chosen to be near enough to n to avoid the recognition of tracks from background sparks and at the same time low enough to avoid loosing tracks with a very poor spark contents. One variation of the program automatically decreases the threshold from a maximum to a minimum value during the search . Program variants also exist where the half-road width d is recalculated as a function of the track slope, and so on. It is worth emphasizing that algorithms like this are normally coded in FORTRAN as independent subroutines, and may be called to perform their task on chambers of any size and with any number of tracks, for film or filmless experiments.

2.4.2 Complex Patterns

The example given in the preceding section concerns one of the most elementary spark aggregates, the linear track. In spark chamber experiments one has often to face the problem of recognizing more complex patterns, such as tracks having one or more vertices in the chamber volume (V's, kinks, stopping particles), showers, stars, tracks and vertices in a magnetic field etc.

Fig. 7 gives examples of the spark patterns most commonly encountered. The automatic recognition of all these shapes has been successfully achieved.

Fig. 8 shows an event of an experiment on the β parameter of the Λ decay performed and analysed at CERN, which contains four different patterns, i.e. linear tracks, V's, kinks and range measurements.

As the complexity of the picture increases, the difficulties and the sizes of the pattern recognition programs rapidly grow. Complexity may increase for a multitude of reasons, such as topology of the event, background, presence of magnetic field, chamber inefficiency, film quality, optical distortions, multiplicity of chambers, views, tracks, vertices, etc. Today, efforts are being devoted towards the automatic evaluation of pictures of an increasing level of complexity. Methods for the recognition of curved tracks and V's in a magnetic field have been reported in ref. 7 and 8. Techniques used at CERN for a variety of experiments have been reported in ref. 9, 10 and 11.

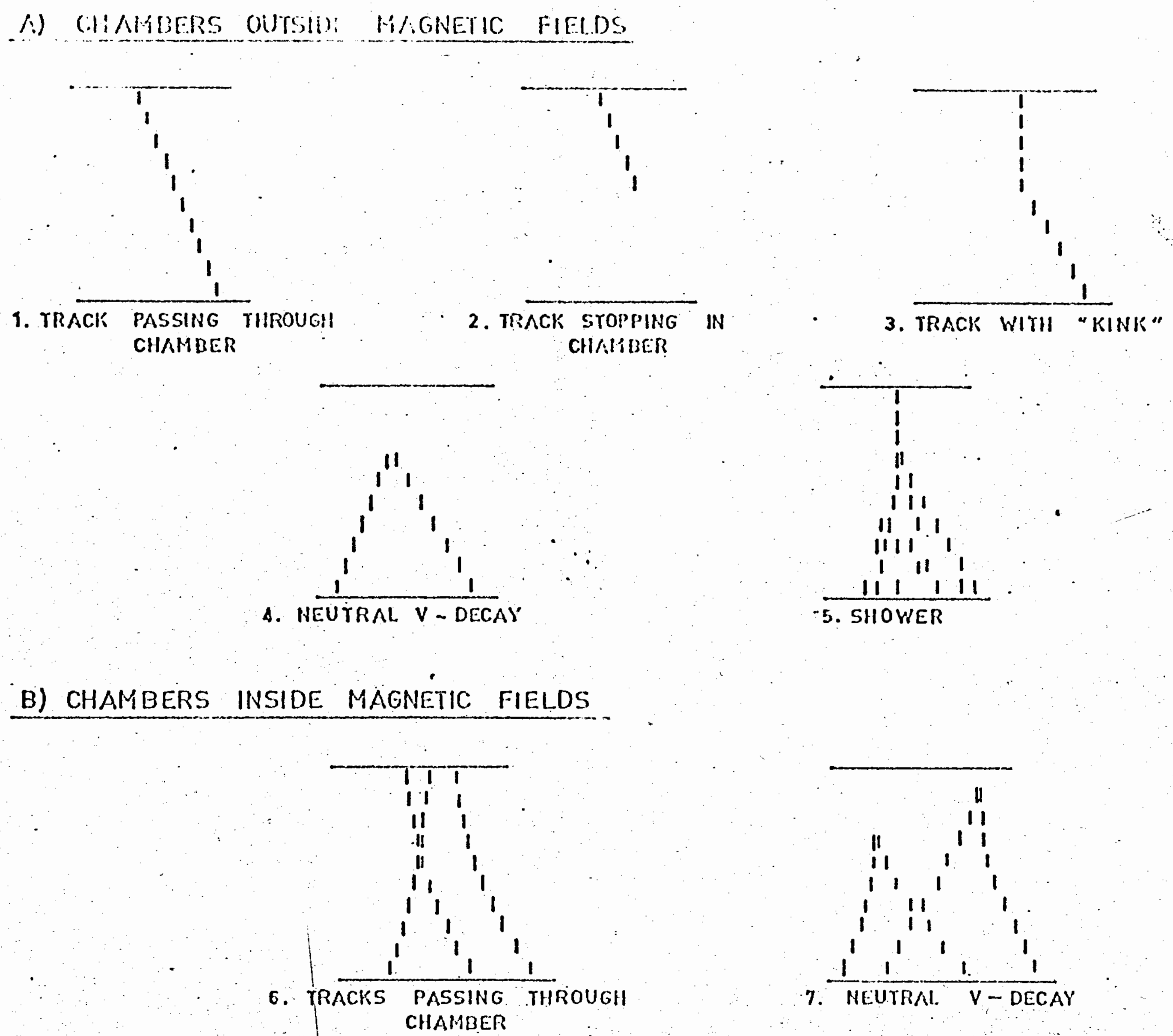

FIG. 7

COMMON TRACK PATTERNS TO BE AUTOMATICALLY RECOGNISED

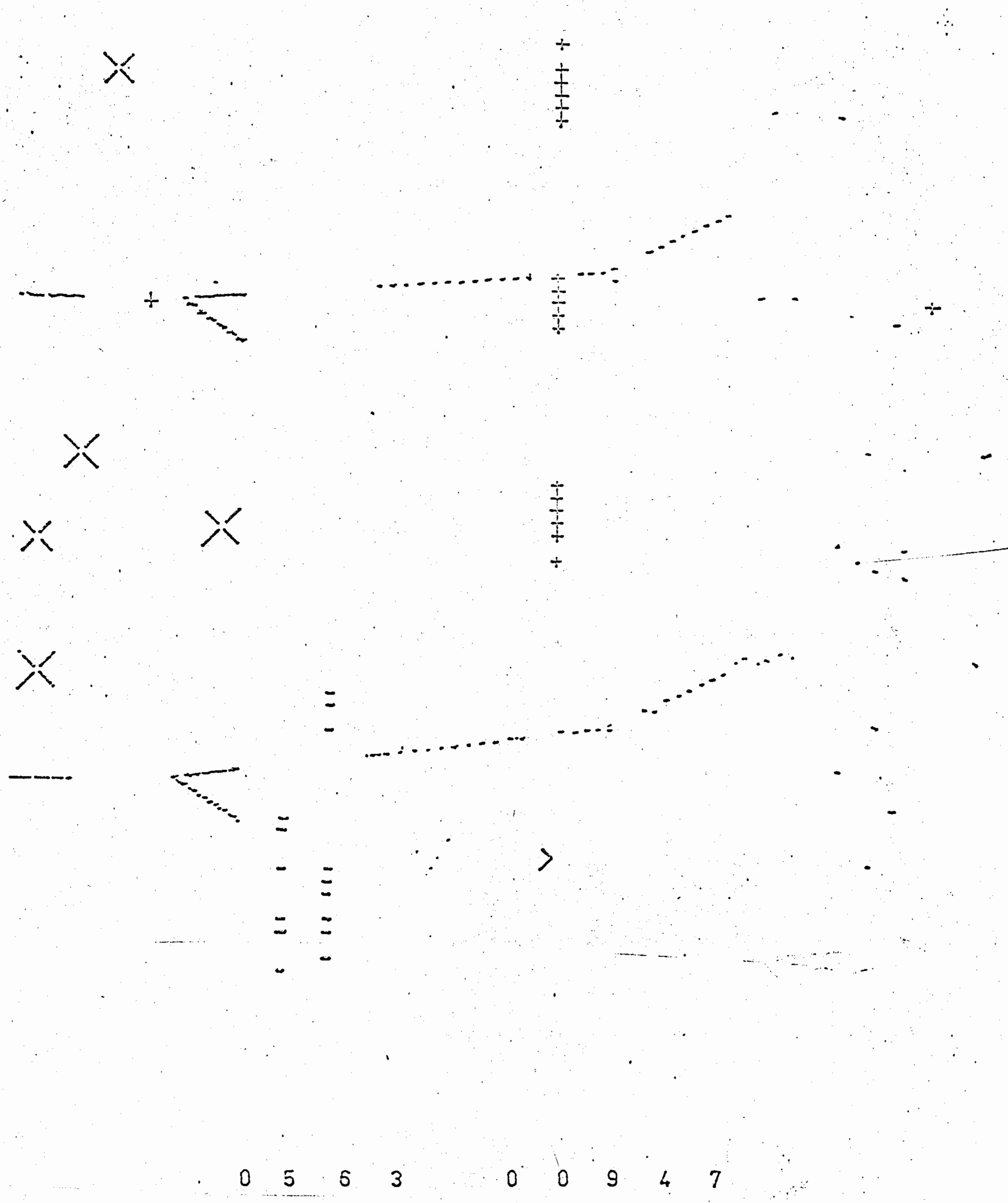

FIG. 8

EVENT CONTAINING SEVERAL TRACK PATTERNS
(LINEAR TRACKS, V's, KINKS, STOPPING PARTICLES)

2.4.3 Use of graphical displays

As soon as one proceeds to very intricate track patterns, the computer begins to show some limitations. This is a reminder that the computer was not specifically designed for two-dimensional pattern recognition.

In order to help the system to overcome these difficulties, it might be desirable to insert a man in the processing chain, in some particular cases. There are, nowadays, very promising techniques which allow man-machine communication via graphical display interfaces. Programs which may facilitate the recovery of events lost by the automatic system have been recently developed at CERN. These difficult events are displayed to an operator sitting in front of a CRT console. He interacts with the program by means of a light pen and a typewriter keyboard. He is asked to supply all information which may facilitate the task of the pattern recognition program. A limited number of light pen operations may be permitted, such as indicating background sparks, pointing out the single sparks belonging to a track, selecting the answer to a computer question among the various displayed choices etc.

By these methods one hopes to recover a good fraction of the rejects. The advantage over manual remeasurements are of many types : homogeneity and high precision of the measurement is preserved, the time involved is significantly less; also by displaying these rejected events one may learn how to improve the programs and therefore avoid further rejections of the same type, one may test new ideas easily etc.

2.5 State of the Art

During the last years the development of reliable film measuring devices and sophisticated data processing programs has made the automatic analysis of spark chamber film a working, viable method suitable for experiments with large numbers of pictures.

The presence of the computer connected on-line to the scanning machine, has made the measuring process fully automatic and highly flexible. Digitizing speeds of the order of a second per frame and precisions of a few microns have been achieved. Because of these speeds and precisions it has often been possible to plan spark chamber experiments which hardly would have been possible otherwise.

The present state of the art can be summarized in two statements.

Firstly, the pioneering age of early developments and successes is over. One is getting organized for mass production of results. At CERN, we have two flying spot digitizers used almost entirely for spark chamber work. We have made our programs as much as possible device- and experiment-independent, thus minimising re-programming efforts, and we have managed to measure about three millions pictures belonging to some 15 different experiments. Recently, it has been possible to perform the automatic analysis of film within a few days of its being exposed at the CERN Proton Synchrotron.

Secondly, one has learned how to process moderately complex pictures. It seems that the price one has to pay for a rapid advance in this way, is to make some concession to the ideal of full automation. Computer time and program complexity can be noticeably reduced by introducing some human guidance. Today, there are two places where the man can profitably help without creating serious bottlenecks : this is at the scanning table, where he can quickly decide which pictures have to be measured and he may add some useful information about the events, and at the CRT display, where he may sort out complex patterns rejected by the automatic recognition programs. This is regarded at present as an acceptable compromise, since it provides a workable, economic solution without sacrificing speed or precision of measurement.

Future trends are closely related to advances in filmless techniques. For simple topology events physicists are already using wire chambers rather than taking pictures. Gradually wire chamber performance will be improved and it will be possible to carry out multitrack experiments with precisions and resolutions comparable with those offered by photographic methods.

At the same time the activity of the automatic film handling systems will be progressively concentrated at the complex end of the job spectrum (non-linear-multi-track events, wide gap experiments, streamer chambers). At CERN, as well as in the U.S. and in U.S.S.R., there are plans for large magnet spark chamber spectrometer systems with photographic read-out and there should be work for quite some time in that field for the film measuring devices.

3. FILMLESS EXPERIMENTS

The advantages offered by the on-line operation of spark chambers over the classical photographic method are quite impressive. Some of them come from the use of wire chambers themselves, some from the on-line computer. The two groups are treated separately in the discussion below, but it is clear that it is the combination of these two components which makes the overall system so powerful.

Wire chambers make film unnecessary and therefore their use removes all sorts of setting-up problems connected with complicated optics. If they are used inside large magnets, large holes do not have to be made in the magnet poles in order to provide an optical path between the sparks and the camera and so the magnetic field is more uniform. During data taking, wire chambers can be pulsed at rates which are one or two orders of magnitude higher than those used for optical chambers. The analysis of the data is simplified: there is no need to operate a film scanner, to recognise fiducial marks or sparks, to decode data box information or to correct for distortions in the optical system. Information about an event is readily available in digital form.

The on-line computer may excercise a positive influence on the regular progress of an experiment in many ways. During the setting-up phase, it may be used to check the performance of the experimental equipment to which it is directly connected, verify chamber alignment, display beam profiles, etc. All this results in an effective decrease in the time which normally has to be spent before starting the actual experiment.

When the experiment is running, the most obvious use of the computer is as a fast device which, with the help of its own large storage buffer, can control the acquisition and transfer of large volumes of data. The recording of information is also simplified because the computer can make use of its own magnetic tape peripheral equipment. All this makes the collection of large <u>quantities</u> of data relatively easy. But the computer may also play an important rôle in improving the <u>quality</u> of the collected data. By performing checks on the data, it may detect equipment failures, abnormal values of some of the data which should then be checked in more detail, systematic shifts in the expected values of certain parameters and so on. This real-time feedback is invaluable and may result in the acquisition of better data.

Finally, the on-line computer can be used to process the experimental data. Depending on the type of experiment, the event rates, the computing requirements and the available processing capacity, one may be able to analyse completely all the data on-line or one may carry out only some calculations on sample events. The calculated results can be conveniently presented to the physicist via digital or graphical displays. The physicist may interrogate the on-line system, asking for one of many possible sophisticated displays, thus making sure that everything proceeds as expected. Alternatively, the availability of physics results during the course of the data taking may suggest changes to the experimental conditions or to the strategy of data collection. This ability to produce some physics results in real-time is a most attractive feature of on-line experimentation and one which is not available with any other technique. Clearly, the on-line computer system is an extremely powerful tool and its potential capabilities have not yet been fully exploited.

To conclude this introductory note one could emphasize the important consequences of computer-assisted experiments in terms of more efficient use of the accelerator facilities. In the near future, it should be possible to organize the experimental activities so that the amount of beam time lost during setting-up periods is minimized and the rate at which useful information is collected is maximized. In all this, the computer is going to play an increasingly central rôle.

3.1 Data Handling Philosophy

Ideally, one would like to see every electronic experiment equipped with an on-line computer which is powerful enough to perform all the important functions mentioned above. But if one tries to look at all this in the perspective of a large laboratory, where many such experiments are on the floor at any one time each one being at a different stage of progress and having its own characteristic data rates etc., one realises that there is no simple, economic and safe solution at hand.

There are large fluctuations of computing demand as the experiment proceeds and from one experiment to another. The solution which consists of giving each experiment its own private computer chosen to cope with that experiment's peak demand is relatively simple and safe but certainly not economic. On the other hand, a fully centralized, multi-experiment on-line computer complex which can offer each experiment the services it requires with sufficient reliability does not seem to be practicable in the immediate future. Systems of this type have been successfully implemented in other fields, for example in low energy nuclear physics, where the requirements imposed by the type of experiment and the data rates are fortunately matched by what the computer industry is able to offer at the moment. So, while the high energy physicist waits for the super-computers of to-morrow, some interesting compromise solutions are being adopted. At CERN, for example, the present tendency is towards the assignment of a small-to-medium size computer to each on-line experiment. This is used for the essential data acquisition tasks doing a minimum of experiment monitoring; then the bulk of the data is processed off-line by the central computer facility. An attempt is also being made to link small computers to the central facility in such a way that the extra computing capacity needed from time to time for the analysis of event samples can be supplied directly to the experimental area(FOCUS project) These methods will be described in the next sections.

To day, with some rare exceptions, "on-line" experiments are evaluated off-line. In some cases the computing requirements are so large that a computer capable of doing everything on-line does not exist now or in the foreseeable future. In the great majority of cases it would be too expensive to make the necessary computing power available on-line. With the help of FOCUS-like systems or by any other means of accessing remote computer installations (data links, "bicycle-on-line" etc.), one can supply limited computing capacity to carry out some immediate calculations on sample events, thus ensuring the correctness of the recorded data. In the most common data-handling scheme, the small on-line computer is merely used as a setting-up aid, as data acquisition and recording device and as a quality control instrument.

3.2 Programming the Computer and on-line

Many different models of computers are being used to service on-line experiments, but the following characteristics are typical : core memory from 4 to 16 K words of 16-32 bits and a cycle time of one or a few microseconds; central processor with fast fixed point arithmetic and logical operations, flexible input-output system with fast buffered channels, direct memory access and multi-level interrupt facilities; two or more magnetic tape units, card or paper tape handling equipment, on-line typewriter and some display units (CRT, plotter, slow line printer). Small disk memories have been introduced in the most recent systems and allow increased programming flexibility. Examples of computers in use at CERN for on-line experiments are the IBM 1130, 1800, 360/44, SDS 920, PDP 8 and PDP 9.

Fig. 9 shows the typical configuration of an on-line computer system. One may notice the similarity to the system described in section 2.2 for the FSD operation.

The on-line computer is programmed to perform its various tasks under the control of the interrupt facility. An interrupt is an electronic signal sent to the central processor from the experimental equipment or from any component of the computer system (channel, typewriter, tape unit etc.) to indicate that certain conditions have been met. For example, that the coordinates of an event are ready for transmission to the computer or the writing of a record on a magnetic tape is terminated, etc.

The interrupt causes the processor to stop any current action and to give control to a sub-routine which identifies the reason for the interruption and then takes the appropriate action. In a flexible priority interrupt system, interrupts may be honoured immediately or action may be delayed depending on their level of priority. The various priorities are assigned to the interrupt conditions taking into account all the combinations of interrupts which may occur.

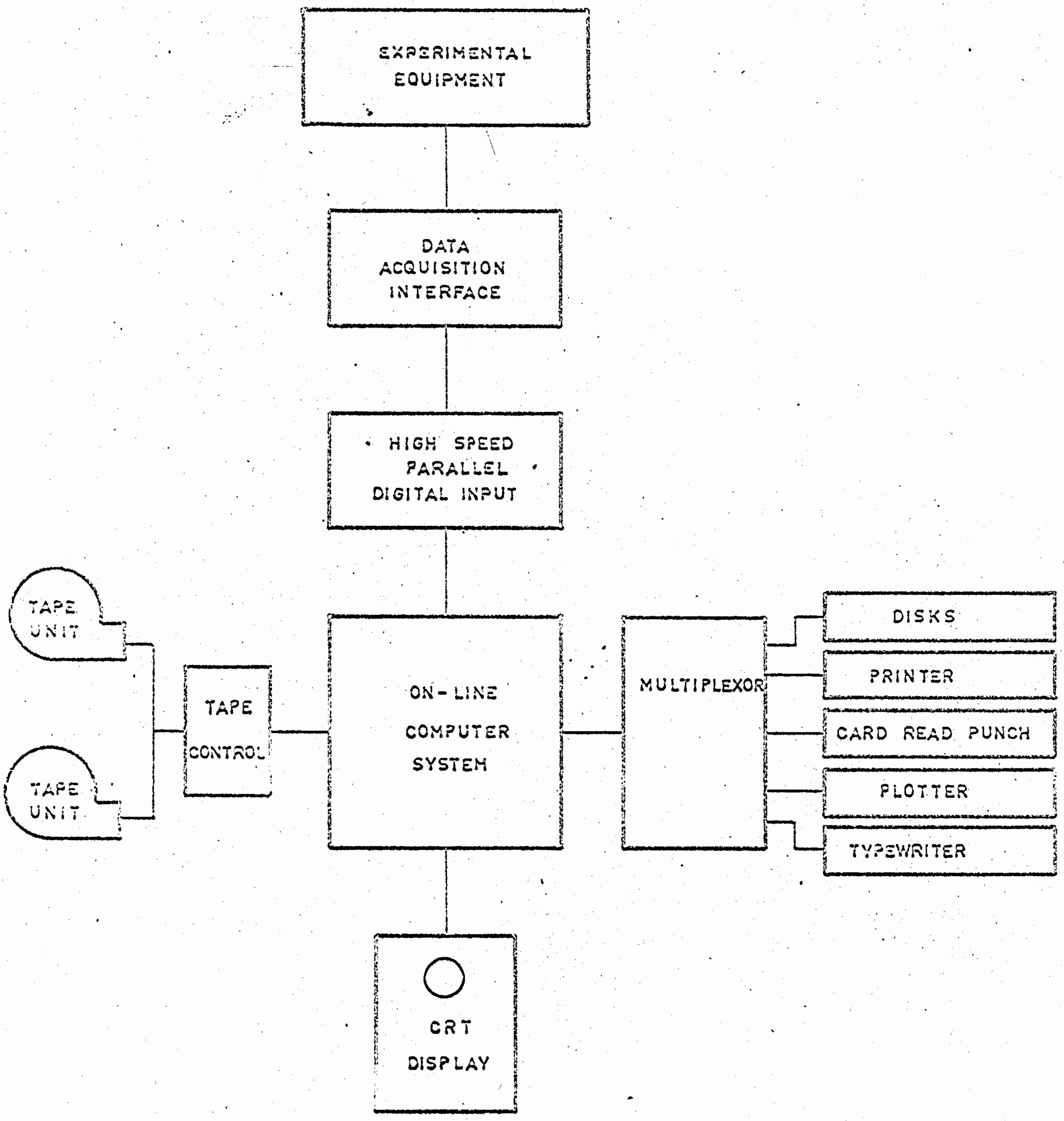

FIG. 9
ON-LINE COMPUTER CONFIGURATION

One proceeds by assigning the highest priorities to the primary functions such as the input of experimental data or the output of events onto tape, and assigning the lowest priorities to the activities connected with slow peripheral equipment (e.g. plotter, line printer) or with manual interventions (e.g. typewriter). One level of computer activity corresponds to each level of priority.

At any one time the computer carries out calculations at a certain level. Any higher level interrupt causes the control to be transferred to a more urgent activity. When the interrupt has been honoured the computer carries on with the task which has the next lower level priority. The lowest possible level is normally used for background computations such as reconstruction of some events, evaluation of certain kinematic quantities etc. Since the interval between accelerator pulses is used for data checks and recording operations, it is often an advantage to synchronize the computer and the accelerator cycle by providing an interrupt signal when the cycle begins.

Many other interrupt signals may be sent to the computer from a variety of instruments in the experimental area. Conversely, the computer can output electronic pulses to control external equipment.

Coding the programs is a non-trivial task. Timing problems have to be taken into account; to speed-up the execution of the various on-line activities, a considerable portion of the code is written in basic assembly language.

When disks are available, the program overlays are normally stored on them and are loaded into central memory only when they are needed. Only the most frequently used routines stay permanently in core memory. A part of the memory is reserved for an input buffer which receives the data read during the accelerator pulse. This data consists of the readings of scalers, parameter and pattern units, scintillation counters and wire chambers.

When the accelerator interrupt signals the end of the burst, scanning of the buffer begins. Several kinds of statistics are kept (for example the number of events per pulse, the number of wires hit in each plane etc.) and a variety of simple consistency checks are applied. If some check fails or if some result is obviously incorrect the computer prints out an appropriate warning message for the operator who may in turn ask the computer to output summaries from time to time.

The experimentalist may communicate with the computer in many ways (typewriter, sense switches, card reader, etc.). He may request that specified programs be loaded into core and executed one at a time. Generally these optional programs contain several tests and analyses of the collected data, output of histograms of beam profile, wire chamber alignment and resolution, numerical and graphical output of spark patterns, various tape handling utility programs etc.

The man-machine communication is greatly facilitated if a CRT display is used, because this device is capable of showing on its screen large amounts of information in graphical form, i.e. the form which is best assimilated by eye. If a light-pen is also available, then the experimentalist may use it as a powerful means of input to the computer and the potentialities of the on-line system are much enhanced. For example one can point at a track and have it reconstructed by the computer, one can indicate a part of a histogram and have it enlarged, or one may find it useful to plot some quantities in a variety of ways in order to understand some abnormal behaviour of the event detection etc. However, the use of this expensive equipment is still quite limited and its potential applications have not yet been fully explored.

All the recorded events have to be automatically recognised by the second stage programs. CRT-based human guidance before the pattern recognition, and recovery procedures afterwards are technically possible but may be impractical in view of the very high number of events involved. This precludes any kind of manual reduction; all the recorded triggers normally go through the automatic analysis sequence.

The techniques adopted for track and event recognition are basically the same as those used for film evaluation. The stereo-views of optical chambers are replaced by the uncorrelated groups of coordinates from the two orthogonal sets of wires.

The pattern recognition programs may at the moment look simpler for wire chambers because these detectors have only been used so far in experiments with simple event topology.

The savings to be gained from the use of wire chambers are confined to those programs in the first and third stages which recognise the sparks and reconstruct them in real space.

The status of the software currently developed for on-line experiments clearly indicates that the pioneering age is not yet over. Programs are tailored to the respective experiments, flexibility and sophistication have not yet been seriously attempted and valuable experience is still being accumulated. Soon, the software system will have to be more carefully planned, and the experience gained with films will be very helpful.

There is still quite a lot to be learnt in those areas which are particular to on-line experimentation, e.g. data acquisition bottlenecks, effectiveness of the real-time feedback, etc. When the computer is directly connected to the experimental equipment, any limitations on the data flow through the system may slow down the wire chamber operation. So the same limitations which would have reduced the throughput of a flying spot digitiser now cause the loss of experimental data. These limitations are generally related to the speed and capacity of computer's central memory, magnetic tapes, disks or any other storage media. At present, wire chamber requirements are growing faster than computer performance. Often the computer used for one experiment is too small for the next. If the computer is sufficiently powerful, then the bottleneck may move to tape operations. Experiments are being planned which could fill a magnetic tape in less than five minutes. This raises big questions of data management, of temporary and permanent storage of the experimental data at the various data processing stages, of processing speed, of program optimization, of machine language coding etc.

3.3 Interconnection of Computers

One way of providing the possibility of real-time feeding back of partial physics results is by connecting the small computer by remote access links to a large multiprogrammed system. Such data transmission links have been used in recent years to connect small computers to large ones. At CERN, some time ago, one experiment using sonic spark chambers was controlled on-line by an SDS 920 computer which was in turn connected to the large CDC 6600. [12)]

The SDS 920 collected the raw data, reduced it by making some simple checks and stored it locally. For a few hours each day, the reduced data was also transmitted to the large computer through the data link [13)] and was analysed. The large computer displayed some of the results, and it was impressive to see, for example, missing mass spectra plotted on a CRT and continuously updated at the same time as data was being collected.

More recently, it has been appreciated that this type of service must be available for several on-line experiments, simultaneously. A project called FOCUS [14] (an acronym of "Facilities for On-line Computations and Updating Services") is being developed in the data handling division of CERN. It is based on a CDC 3100 computer equipped with 8M characters of disk memory which will be inserted as a data-traffic switchyard between the various small computers and the big ones. Its task is to collect requests for service from the on-line users and if necessary to transmit programs and possibly the data to be processed to the 6000 series computers for execution. Requests to FOCUS are easily specified on teletype and may include 1) compilations and updating of programs, 2) execution on the large computer of selected user programs with specified data files, 3) temporary accumulation of sample events coming from the on-line computers via data links, 4) execution of analysis programs on these experimental data, 5) return of desired results to the users via their small computers or on the FOCUS teletypes etc.

This type of facility should be very useful for the on-line experimental groups both in the setting up phase when they have to check out their equipment and their program at the same time and in the data taking phase when they will be able to execute a variety of programs on sampled events, changing analysis conditions from their teletype in a very flexible way. It should provide a valid check on the quality of the data recorded and further means of ensuring efficient control over the progress of the experiment.

Compared to the direct connection between the small computer and the large one, the FOCUS system should offer the same advantages (availability of computing power, compiler, assembler and library routines of a large central installation) and overcome the disadvantages experienced (difficulty of access during development and testing of hardware, fixed schedule of time during data taking, lack of facilities to modify programs during on-line runs, inefficient use of central computer etc.).

FOCUS is meant to provide a regular service, 20-22 hours per day. It will have access to the two compatible CERN central computers (6600 and 6400) for the execution of user programs. No execution of programs will occur in the 3100 which will only be used for file manipulation. From the point of view of the central computers the 3100 is just an input/output station. Job input files received from the 3100 are added to the queue of waiting jobs, but are assigned a high priority. It is believed that an adequate response time will be obtained with a minimum of modification to the present SCOPE operating system.

3.4 Conclusion and Trends

Wire chambers connected on-line to computers seem to form an extremely promising combination for the years to come. The physicists who have had a chance to work with such systems describe their unique features in enthusiastic terms. It is certainly of utmost importance to be able to change the experimental conditions during a run, thus making best use of the accelerator facilities. But physicists also appreciate the practical and psychological advantages of seeing the results of the experiment soon after the accelerator run and of having the delays between the design of the experiment and the publication of the results cut down.

In view of the trend towards high-statistics experiments and the consequent important rôle of spark chambers, these techniques should be used in future by a growing number of experimentalists.

New progress has to be expected in the flexibility and sophistication of the data handling systems (better software, more facilities, improved pattern recognition etc.) .

One should also see the computers being more extensively used for the automatic control of experimental equipment, performing, for example, systematic checks and adjustments of parameters such as current, voltage, etc. in a variety of instruments.

Physicists will be increasingly interested in having more computing capacity available during on-line runs. This may be achieved by further development of inter-computer connections.

One can also expect a growing interest in the communications means between the experimentalist and the computer. Graphical CRT displays with both input and output facilities seem to have a number of attractive features. If they become less expensive, they could be an ideal tool at the various data handling stages; on-line, as a monitor of the experiment, off-line as a means of seeing and recovering difficult events and as a powerful analysis aid in the last phases of the experiment evaluation.

A synthesis of these trends may be found in the present plans at CERN for the Omega Project. This project envisages a very large magnet with spark chambers filling the gap between its poles. It would be operated as a kind of "electronic bubble chamber" with provision for optical and direct digital read-out of spark positions. The data handling system proposed for this project would use the various facilities described in these notes both for the automatic analysis of films and the evaluation of on-line experiments.

References

1) P. Zanella, "Automatic Scanning - Spark Chamber Developments" Proceedings of the 1966 International Conference on Instrumentation for High Energy Physics, Stanford, California, U.S.A. September 9-10, 1966.

2) W.G. Moorhead, paper presented at this school.

3) H. Rudloe, M. Deutsch, T. Marrill, "PIP - A Photo Interpretive Program for the analysis of spark chamber data" Communications of the ACM, 332, 1963.

4) P.M. Blackall, G.R. Macleod, P. Zanella, "A Program for the automatic scanning of spark chamber film", Proceedings of the Int. Symposium on Nuclear Electronics, Paris November 25-27, 1963 Vienna, AIEA, 1964

5) P.M. Blackall, B.W. Powell, P. Zanella, "The automatic analysis of 200,000 spark chamber pictures using the CERN HPD" Proceedings of the Conference on Programming for flying spot devices, Bologna, October 7-10, 1964, CERN Report 65-11.

6) T.F. Andersson et al. CERN internal report, DD/DP/67/4

7) P.M. Blackall and P. Zanella - CERN Report 65-11

8) J.C. Lassalle and P. Zanella - CERN Int. Report DD/DP/65/10

9) P.M. Blackall, G.R. Macleod, P. Zanella, CERN Int. Report DD/DP/65/2

10) R.A. Bowen et al. CERN Int. Report DD/DP/65/11

11) R.A. Bowen et al. CERN Int. Report DD/DP/67/5

12) T.R. Bell et al. CERN Report 67-31

13) N. Marciano, CERN Report 65-40

14) P.M. Blackall, CERN Int. Report DD/CO/67/7

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В Школе ОИЯИ по применению ЭВМ в задачах экспериментальной физики, проведенной с 5 по 19 мая 1968 года в г. Алуште, были прочитаны следующие лекции:

М.Г.МЕЩЕРЯКОВ (ОИЯИ) Вводные замечания

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ЭВМ в задачах экспериментальной физики

Е.П.КАЛИНИЧЕНКО (ОИЯИ)
Структура современных ЭВМ

А.А.КАРЛОВ (ОИЯИ)
СДС-1604А и организация ввода-вывода на этой машине

В.Н.ПОЛЯКОВ (ОИЯИ)
Вопросы сопряжеиия ЭВМ с внешним оборудованием

Д.ЛОРД (ЦЕРН, Швейцария)
Применение малых ЭВМ в экспериментах на линии

С.С.ЛАВРОВ (ВЦ АН СССР)
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Язык ФОРТРАН и программирование на нем

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Система математического обеспечения ЭВМ БЭСМ-6

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Операционная система СКУОП для СДС-6600

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Применение ЭВМ в спектрометрических экспериментах ядерной физики

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Осциллограф со световым карандашом как средство связи человека с ЭВМ

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III. Устройства и программы обработки информации с пузырьковых камер

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Полуавтоматические и автоматические устройства обработки фотографий

В.Д.ИНКИН (ОИЯИ)
Прибор для автоматического измерения фотографий с пузырьковых камер на базе механического сканирующего устройства типа "бегущий луч" (НРД)

В.Г.МУРХЕД (ЦЕРН, Швейцария)
Измерение фотографий с помощью НРД

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