The Analysis of Track Chamber Photographs Using Flying Spot Digitizers

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A vast quantity of data pours from the experiments on particle accelerators throughout the world. For example, over 300 000 photographs per week came from the three bubble chambers operating on the CERN PS at the end of 1965. The conventional method of processing these bubble chamber photographs is for each one of them to be examined ('scanned') to see whether it records an interesting particle interaction. The interesting photographs are then passed to hand operated measuring machines to obtain precise measurements of the particle trajectories recorded on the film. Similar measurements are carried out on photographs taken in film spark chamber experiments.

This article on the Flying Spot Digitizers at CERN describes one of the most fruitful attempts to speed and make more accurate the process of analysis of bubble and spark chamber photographs. There are two types of Flying Spot Digitizer at CERN — the HPD or Hough Powell Device (named after Professor Hough and the author who, together, initiated the development in 1959) and Luciole, a further development initiated by Professor Kowarski.

On the afternoon of 24 July 1965, measurements were completed on the last pictures from the first bubble chamber experiment to be measured on the mechanical Flying Spot Digitizer at CERN. The previous two weeks had seen the completion of the third and fourth spark chamber experiments processed using the flying spot method. These events marked, for me, the end of the second, and probably the most difficult, phase in the development of this technique. To reach this happy state of affairs had taken us nearly six years. It has developed from a part-time activity for one or two people into a full-time activity for more than thirty people in the Data Handling Division, to say nothing of the many people from Track Chambers and Nuclear Physics Division now involved with the utilization of the system.

If a date can be attached to the start of the HPD and Luciole projects, it should be 21 September 1959 when Paul Hough, who was then a Professor of Physics at the University of Michigan, arrived at CERN to spend a Sabbatical leave working on data processing for bubble chamber pictures.

Encouraged by Lew Kowarski (then Head of the Data Handling Division) and Yves Goldschmidt-Clermont (then Deputy Head of the Division) we spent a year doing primitive tests and evolving what, at the time, were openly called 'crazy ideas'. However, by September 1960, the main ideas had evolved and the first tests had been encouraging. This first phase ended in May 1961 with the successful operation of a prototype device at CERN, thanks to a collaborative effort involving members of the Lawrence Radiation Laboratory, Berkeley, and the Brookhaven National Laboratory (where Hough now worked) in the USA, the Rutherford Laboratory in England and CERN itself. The outcome was a decision at each of these Laboratories to move into phase two — the development of devices of this type for production use. (The CERN prototype was always foreseen as for experimentation only.) The aim of production use, I feel, has now been realized at CERN and we should enter the third phase, which I would define as a consolidation of our position. By this I mean the analysis of more and more experiments using the Flying Spot Digitizers and a steady improvement in the techniques we use.

How pictures are processed

The aim is to reduce as far as possible the human intervention in the analysis of bubble and spark chamber photographs. With the conventional IEP (Instrument for the Evaluation of Photographs) measuring machines an operator uses the machine to make precise measurements on the film. With the Flying Spot Digitizers, the role of the machine is increased — it makes its own precise measurements and the operator provides help for those experiments which are too complex to be analysed by the machine alone.

The machine can be made to operate automatically and is faster than the average operator. This led to a second decision that, as far as possible, any help from the operator would be prepared in advance as a separate operation so that once the machine began a sequence of measurements, the measuring would not be hindered by the operator's speed.

These aims have been realized in the following way. Attached to a computer is the Flying Spot Digitizer, which explores the whole of each photograph with a small spot of light, about 0.015 mm in diameter (Fig. 1). Each time the spot of light encounters something black on the film, the coordinates of its centre are transmitted to the computer for examination. The computer program, which has been specially prepared to recognize specific patterns on the pictures which are being examined, is

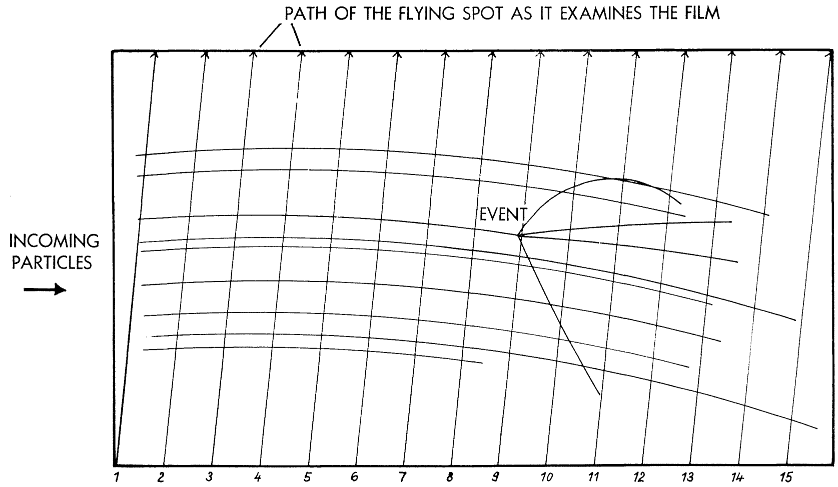

Fig. 1. A schematic representation of how the pictures are scanned. In practice, the lines representing the path of the flying spot are much closer together and the flying spot travels across about 1500 times to cover the whole picture.

able to search through the coordinates corresponding to a given area on the photograph, identify a pattern (such as a cross), which it expects to find there and compute the position of its centre (Fig. 2).

There is nothing very magical about this operation which allows the computer to 'see' a certain shape on the film. The program is merely a means of specifying in advance what steps should be gone through at certain times, which regions should be searched, and what one expects to find there. If something unexpected occurs, the computer is no help. If in a certain region one expects to find a cross and in fact it lies just outside the region, nothing will indicate that it has just been missed ; the computer will merely say that nothing was found.

For each experiment the procedure is similar though not identical. A program is prepared which specifies the regions in which certain patterns are to be expected

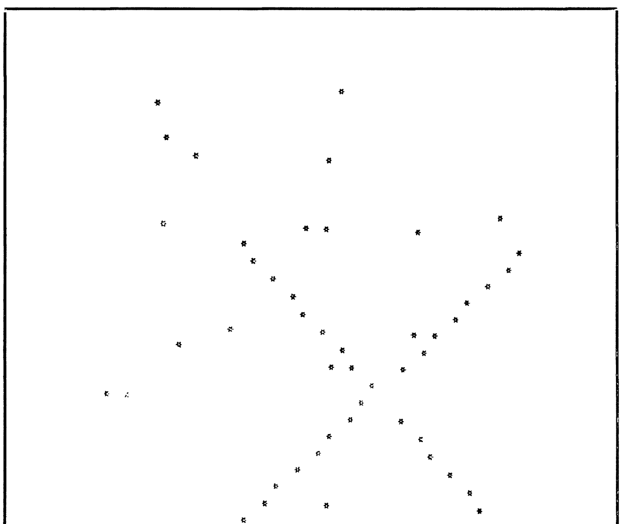

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Fig. 2. An example of a reference cross within the region of the film being examined by the flying spot, together with random digitizings coming from background on the film.

and all coordinates falling inside those regions are inspected by the program to see if they constitute a part of the expected pattern.

The computer program has a second important role to play and this is the control of the sequence of events. Once the operator has loaded his roll of film into the Flying Spot Digitizer, the computer takes over all control. In addition to processing the pictures, the computer controls the advance of the film from one picture to the next, checks that the next picture is the correct one, decides whether any special procedure is necessary (such as rescanning the picture) and prints out a summary of what happened for each picture.

Scanning, Measuring and Guidance

For some of the experiments we have analysed using spark chamber photographs, the patterns of tracks have been simple enough to allow a completely automatic processing. In other words both the selection of those pictures which should be measured (the process normally called scanning) and the measurement itself were carried out simultaneously by the machine. Because the coordinates sent to the computer are of high precision, the measurement stage has already been carried out before it has been decided whether or not the picture is one for measurement. The role of the computer program is then only to recognize which coordinates belong to the interesting features on the picture and to retain them for the subsequent stages of analysis. If the program rejects a picture as not meeting the specifications, the reasons for failure are given, the measurements are thrown away and the machine proceeds to the next picture.

For many types of experiment (such as bubble chamber experiments) we are not yet able to provide a computer program which can do the automatic recognition of interesting pictures. To overcome this difficulty, we use what we have called 'guidance', which involves providing the program in advance with sufficient information about the pictures to reduce the problem to a complexity we can manage. In effect, it amounts to finding a method which eliminates most of

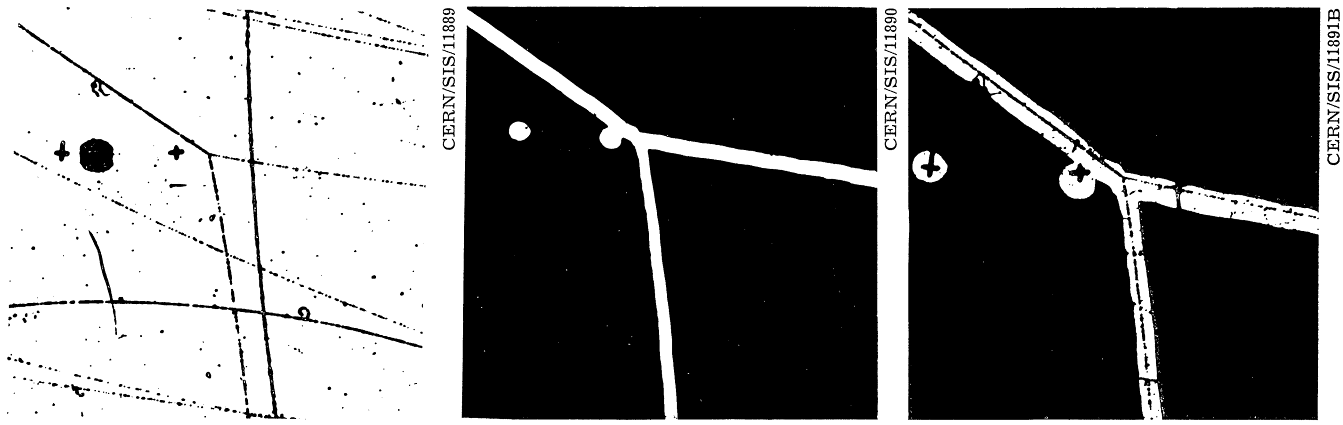

Fig. 3. a) This is the original photograph which contains a simple event.

b) A 'mask' is prepared which serves to hide the background tracks.

c) When the mask is superimposed on the original photographs, the flying spot can see only the tracks corresponding to the event or in the immediate vicinity of the event.

This idea of selecting the area of the film which the flying spot is to examine, is still maintained but now the computer selects the area, after being informed by several 'rough digitizings' where the interesting event occurs on the film.

the unwanted background tracks in advance so that what remains belongs mainly to the tracks one wishes to measure. (With spark chamber pictures this is usually done already in the process of selecting the data in the experiment itself.) From there it is not too difficult to select correctly the points belonging to the interesting tracks and to derive from them the desired information.

At a very early stage, we saw this guidance in the form of a mask as illustrated in Fig. 3. Using this method, coordinates would reach the computer only from those regions in the immediate vicinity of the desired tracks. The masks would have been prepared beforehand and automatically superimposed on each picture at the time of measurement. Before long, it was seen that a much easier and more flexible method of doing this would be to define the approximate position of each track by means of three points (or rough digitizings) which would allow the computer program to do its own selection by computing a curve through the three points and then selecting only those coordinates from the flying spot digitizer which lie in the vicinity of this curve. This is how we now operate for bubble chamber experiments and three scanning tables ('Milady' scanning tables), equipped in this way, are in operation. The operator searches the film for interesting events and when one is found, the number of the picture and the rough digitizings are registered on punched cards which subsequently provide the computer program with its guidance to do the precise measurement of the events.

We have also done one experiment which may be considered as a case of 'minimum guidance'. Here, spark chamber pictures which resembled very simple bubble chamber pictures were to be processed (Fig. 4). In particular, the number of tracks on each picture did not exceed 6 and of these 4 represented the event. Because of this feature, we were able to write a program which needed to be provided only with a list of the pictures where events occurred and the gap numbers in which the vertices were located.

HPD and Luciole

I have so far avoided distinguishing between the two devices — HPD and Luciole. It has probably become clear that a major part of the ingenuity required in using flying spot digitizers lies in the writing of the computer programs. The digitizer itself has to provide the program with as faithful a representation of the picture as possible, it is the writer of the program who really has to solve the problem of what that representation means.

As far as the programs are concerned, there is very little difference between the two devices — indeed pieces of program written for one device are used for the other and vice-versa. Both provide coordinates in a similar manner, both scan the film in a similar manner, both are controlled by the computer in a similar manner. The main difference lies in the mechanism for producing a spot of light to scan the film. With the HPD the flying spot is produced mechanically and with Luciole it is produced using a cathode ray tube. This difference results, at least for the present, in a greater accuracy for the HPD and, therefore, application to large film formats such as bubble chamber pictures is

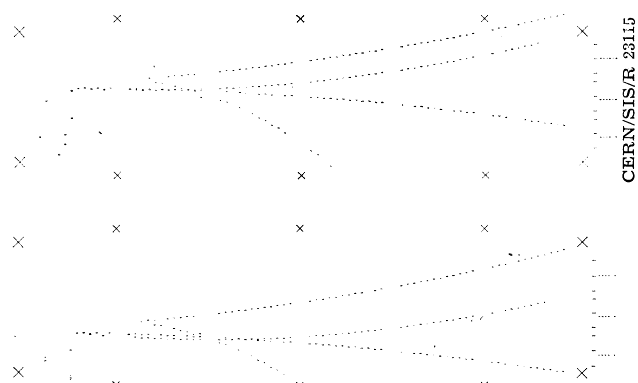

Fig. 4. An example of the decay of two neutral V particles in the CERN-E.T.H. magnet spark chamber (Experiment 3 in Table 1).

Type of experiment	Physicist in charge of experiment	Detector	Processing device
1. $\pi^{\pm} + p$ $p + p$ scattering	Harting	Spark Chambers	HPD
2. $\pi^- + p \rightarrow Y^- + K^+$	Lundby	Spark Chambers	Luciole
3. $K^- + p \rightarrow K^0 + n$ $\pi^- + p \rightarrow K^0 + K^0 + n$	Michelini	Spark Chambers	HPD
4. $\pi^+ + p \rightarrow \Sigma^+ + K^+$ $K^- + p \rightarrow \Xi^- + K^+$ parity determination	Rubbia	Spark Chambers	HPD
5. $\bar{p} + p$ at 5.7 GeV/c all interactions giving 4 charged secondaries	French	Bubble Chamber	HPD

Table 1.

easier. Secondly, the method used for deriving the coordinates with Luciole necessitates a calibration which is more frequent and more complex than that needed for HPD. However, since this is carried out using the computer, it is not a very serious complication.

The Luciole project was initiated in the Spring of 1962 by Lew Kowarski as a further development of the HPD system aimed in particular at spark chamber picture analysis. It was clear at that time that spark chamber experiments could be analysed using HPD alone but it was also thought that with the very high rate at which spark chamber pictures can be produced, it would be desirable to foresee a greater capacity than that allowed by the HPD project alone. Moreover Luciole might, in time, offer substantially higher processing rates than the mechanical system. It was also clear that we would gain by making the machines 'look alike' to the computer so that experience gained with one instrument would be of benefit in the use of the other.

At the moment Luciole has been used for one experiment, but the experience gained, coupled with that derived from programming for the HPD system, does not leave any doubt about its future as a useful device.

Results to date

In Table 1 the experiments which we have processed to date are listed, together with some details of the techniques used and the size of the analysis problem. Although all of these experiments are now finished in so far as we are directly involved, the assessment of the results is still in progress for the last three at the time of writing.

To give an idea of the performance, I shall describe some of the checks which we have made on our results to verify that no undesirable effects were present. For the first spark chamber experiment, a large number of hand measurements had also been made so that a comparison between the two methods was possible. In Fig. 5, we show one such comparison. The measurement of the incoming track to the target and of the two outgoing tracks allows one to calculate the position of their intersection inside the target. Only with perfect accuracy would the three tracks meet at a single point, and therefore the extent by which they deviate from this ideal is a measure of the quality of the results. In the figure, these deviations are plotted for data from a few hundred pictures so that the width of the histogram is an indication of the average quality of the measurements. It is clear that the automatic measurements in this case are more accurate than the hand measurements. According to our estimates, the histogram for the HPD indicates an accuracy of $\pm$ 0.006 mm in determining the position of each track on the film.

Another, and most important, part of this study consisted of checking that the automatic selection as to which pictures should be accepted and which should be

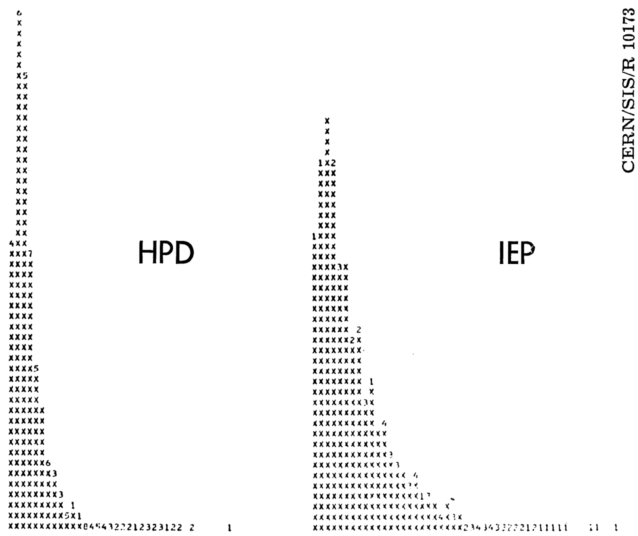

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Fig. 5. The distributions compare the accuracy of HPD and hand measurements on spark chamber pictures from an experiment on π-p scattering. The measurements were performed on three tracks reconstructed to form a single vertex. The width of the distribution is a measure of the accuracy of the method ; the narrower the distribution the more accurate the measurement.

Processing speed	Number of pictures or events processed	Type of processing	Completion date
1200/h	200 000 pictures	Automatic selection and measurement	March 1964
1800/h	100 000 pictures	Automatic selection and measurement	February 1965
120/h	19 000 events	Automatic measurement (with minimum guidance)	July 1965
320/h	56 000 pictures	Automatic selection and measurement	July 1965
70/h	21 000 events	Automatic measurement (with full guidance)	July 1965

rejected was reliable. Comparison made with several thousand spark chamber pictures showed that the agreement between the human and the machine was about 92 %, the discrepancies coming mainly from conditions which we considered to be legitimate (such as the failure of the Flying Spot Digitizer to detect, reliably, a particularly faint spark on the film).

For the bubble chamber experiment too, a particularly thorough study of the results is being made. Here again, a rather better accuracy is obtained with the automatic device. But our main concern has not been to establish the average accuracy, which we expected to be good, but rather to discover whether occasional large errors were occurring which would lead to a false interpretation of an event. This might result from a track being incorrectly measured and, as a result, being assigned a too high momentum. Without necessarily giving obvious sign of error, it might nevertheless give rise to a spurious interpretation. Table 2 summarizes our present knowledge based on a comparison of 691 events measured with both the IEP and the HPD. The small number of discrepancies and the proportion of these ascribed to incorrect IEP measurements indicates that the reliability of the automatic measurements approaches, and may soon be better than that of the hand measurements.

	Number	%
Compared events	691	100
Discrepancies	23	3.3 ± 0.7
HPD, false interpretation	11	1.6 ± 0.5
IEP, false interpretation	7	1.0 ± 0.4
Unsolved	5	0.7 ± 0.3

Table 2. A comparison of HPD and IEP measurements.

It is not the aim of this article to provide a detailed assessment of the results we have obtained but I hope that these few examples will give a general idea of the work that has been done and help to show that the results are very favourable.

The future

During the time that work has been in progress no less than eight other Laboratories have decided to install similar measuring devices (making twelve Laboratories in all). Many of these new machines will soon be in operation and will add very substantially to the processing capacity currently available for bubble and spark chamber pictures.

Simultaneously with the development of the method outlined here, efforts have been made, first at Brookhaven and subsequently at Berkeley, to write programs which will perform a completely automatic selection of interesting events in bubble chamber pictures. We intend to start work on this difficult problem here also in the near future but, although the results obtained have been encouraging, it is too soon to envisage the automatic selection of events for any but the simplest types. How far we can go in this direction is by no means clear but with the present system, using various degrees of guidance, we must certainly extend our variety of experience as far as possible. This is necessary to come to a full appreciation of the problems which may occur and to develop confidence in dealing with them. Only when that stage is reached can we claim to have an analysis system which competes in every way with the hand operated machine.

So, while keeping a considerable interest in the developments toward complete automation, our immediate aim is to achieve greater adaptability to different kinds of experiment and to improve further the quality of the results which we produce. It is for this reason that, at the beginning of this article, I defined the next phase of our work as one of consolidation.