Title
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STATUS OF THE LRL FLYING SPOT DIGITIZER

The Berkeley Flying Spot Digitizer (FSD) includes a Hough-Powell device of the kind first proposed at the 1960 Instrumentation Conference.[1] Implementation of such a device at Berkeley began in 1961, and we reported the measurement of our first event to the Instrumentation Conference in 1962.[2]

Other Hough-Powell devices have been operated at CERN and Brookhaven, and now a new wave of hardware fabrication has made many such devices almost ready to begin physics operations. The groups at Bologna and Paris have measured and reconstructed events, and others are already digitizing film. Our measurement of events for actual physics use begin in 1963. In these three years of operation, we have measured more than 300,000 distinct events which have been included in various reported physics experiments. Our experience in physics production has extended over three chambers; the Berkeley 72" and 25" Hydrogen Bubble Chambers and the Brookhaven 80" Hydrogen Bubble Chamber. In some of the experiments, the chamber has been filled with deuterium. The beam momenta have ranged from 300 MeV/c up to 6 BeV/c.

The FSD at Berkeley has so far been operated in the HAZE mode. In this mode, manual scanning finds wanted events and identifies them for subsequent automatic measurement under computer control. The functions which the scanner performs are: (a) preselection of those frames which contain events of interest, (b) identification of the event type, (c) association of appropriate mass codes with each of the tracks, and (d) identification of the tracks in each of the three views. Once this scanning information has been recorded on tape, computer control of the measurement process is fully automatic.

Recent performance with film from the Berkeley 72" HBC has been about as good as we expect to achieve, without having major improvements to the chamber illumination and optical systems. Let me therefore give some of the rates associated with recent experience using this chamber. This experience comes from two experiments: a 4 BeV/c π^+p exposure, and a 6 BeV/c p p exposure. Only four prong events are being scanned in the π^+ experiment, and about one event is found in three frames. Two-, four-, six-prong and strange particle events are being scanned in the p p experiment, and about one event is found per picture. There are perhaps 12 beam tracks per picture in each experiment.

The scanners find and make roads for about 15 events per hour of actual scan table operation. However, we found that the scanners pace themselves so that only about 3/4 of the time in which they are nominally using the table is actual used for scanning. Once roads have been made, the FSD measures under computer control at the rate of 125 event measurements per hour. Because the computer is directly online, we can evaluate the quality of measurement, and if an apparently random failure has occured in the measurement, the program can immediately request a repeated measurement. This happens in a small percent of the total views measured, so that a net rate of about 110 events per hour is achieved.

Our recent experience for all data has produced a completion ratio averaging about 85%. This means that 85% of the events found by the scanners have been successfully completed by the spatial reconstruction program at the conclusion of their first FSD measurement run. This ratio is not greatly different from that which one obtains with Franckenstein measurements. However examination of individual scanner completion ratios shows that some scanners do very much better than others while some, of course, do worse. We have measured some rolls in which 97% of the events found by scanners were successfully completed. The current average for the 6 BeV experiment is above 90%.

We have studied the performance of an experiment which typifies recent 72" HBC performance. It is neither the best nor the worst. In this experiment, scanners were searching for 4 prong events produced by 3.5 BeV/c π^+ mesons. A proton contamination of about 10% was predicted. The sample studied was 2800 events which have been normalized to a 1000 event sample in Table I for convience of interpretation. Table I shows the distribution of this sample into the various categories. A completion ratio of 85% was observed, and about 80% of the processed events were unambiguously classified by kinematics. The remaining 20% constituted a background which included ambiguous events, and multiple neutral production as well as events having no kinematic fit. There is good reason to believe that ionization measurements can confirm most kinematic selections, and resolve many ambiguities. A reasonable distribution of fits is observed; i.e. the distribution of the events into the various categories is consistent with the physics.

Therefore, we believe that the HAZE mode of operation is running quite well. We expect that additional experiments will be performed in new chambers, and there will be the usual problem of adapting fiducials and camera markings to optimize HAZE performance. The filtering process seems to be in a satisfactory state, since less than 2% of the events are classed as intrinsic failures, i.e., always rejected by filtering. These events very frequently have three or more extraneous beam tracks repeatedly crossing one of the tracks of the event.

The solution to this problem is best achieved by separating beam tracks through the use of beam stepping magnets.

Ionization measurements have been made on all tracks measured since 1964, but we are just beginning to reach a sufficiently stable plateau of chamber operation to understand and make use of these measurements. With the new procedures, we find that we can distinguish tracks whose relative ionization is 1 1/2 times minimum from minimum ionizing tracks. Similar differences can be distinguished up to relative ionizations of four times minimum. Thus the FSD ionization measurements are better than the usual scanner's estimates, although certainly less precise than actual bubble counts with a microscope. We believe that as further understanding is gained of chamber temperature, pressure, and illumination variations it will be possible to further refine the procedures by which ionization measurements are related to relative ionizations units.

I should like to next consider the system consisting of the same hardware and computer, but different programs. This system, which we call DAPR (Digital Automatic Pattern Recognition), is a completely automatic scanning, measuring and analyzing system. There are several reasons why it seems desirable to move on from the HAZE system to DAPR. The results of DAPR operations on most types of events will be as good as HAZE measurements, and in some cases better. DAPR is preferred to HAZE because of its completely automaticity and the consequent absence of fluctuations and biases produced by a large group of scanners working on any one experiment. DAPR is preferred also because it is more economical than other measurement processes. Because no scanners are required, scheduling and control of the experiment is more easily accomplished.

We do not yet have a DAPR system ready for physics use, although we expect to be in production early in 1967. The programs have been developed in prototype form and have demonstrated adequate performance in a variety of chambers and experiments.

When DAPR becomes operational, one mode of FSD use will be fully automatic scanning and measuring. In this mode, film may be taken from the developing tank directly to the FSD and measured without prior scanning of any sort. The DAPR program will produce on magnetic tape a digital abstraction of the significant information contained on the film. Another mode of DAPR operation would allow manual preselection of certain frames, followed by automatic abstraction of data from those frames in just the same manner as if no preselection had occurred. This preselection mode of operation would be applied if events are sufficiently sparse as to make abstraction of all pictures economically unjustified. In experiments involving short tracks such as deuterium recoils, DAPR would be operated with prescanning in which the scanner measures the short stub on the roadmaking digitizer. These measurements of the short track are then carried through to the spatial reconstruction program without further FSD measurement.

Rates of measurement with DAPR will be comparable to rates with HAZE. The HAZE program uses only a relatively small fraction of the total computer main frame time available. DAPR will utilize a large fraction of the computer main frame time during the data abstraction process. Nevertheless, some 30% or so of the overall computer main frame would be available even with DAPR in operation.

The IBM 7094 Model II is the slowest computer capable of operating the DAPR program at these rates. It is therefore the most suitable computer since DAPR requires dedication of all tape units, memory, and discs available on most computers in order to operate efficiently.

The prototype DAPR programs have been operated in real-time and on data from several bubble chamber experiments. I have selected two slides, each illustrating one view of an event. One is from the Berkeley 72" chamber the other from the Brookhaven 80" chamber. Figure 1 shows the actual 72" chamber film image, a graphical presentation of the data contained on the abstraction tape, and a display of those tracks which have been provisionally associated into vertices. It is obvious that some false vertices are found, but just as in the manual scanning process, these false vertices are easily eliminated by comparison between views. Figure 2 contains a similar set of displays for an event from the Brookhaven 80" chamber.

The DAPR process consists therefore of several computer programs. A first track following program controls the FSD and receives digitizings of the film. This program operates in real-time. Other programs operating a few moments after the film measurement combine significant information of tracks measured in the several sweeps of each view, search for provisional vertices, and in the case of Berkeley format film, combine all views into a single record. The result of this processing is a data abstraction tape, which contains all significant data from each measured frame in the film. When a sufficient amount of film has been abstracted, the scanning process is performed on the computer by giving scanning instructions to a special program. We expect that the production scanning will occur at a rate of about 5,000 frames per hour. The result of the scanning process will be a HAZE Library tape which agrees exactly in information content with the present HAZE Library tapes.

In summary, we think that the difficult question of whether digital automatic pattern recognition can be achieved has been answered in the affirmative. We believe this process will be better and cheaper than any other means of analyzing bubble chamber pictures. The abstraction of data from film will yield a reliable and unconfused digital description of the significant information in the film. This digital abstract can be scanned by computers at sufficient rates to make possible exploratory scans without the overwhelming barriers of time and cost that now constrain the experimenter.

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[1] P.V.C. Hough and B. W. Powell., Proc. Int. Conf. Instr. H. E. Phys., Berkeley (Interscience Publishers, N.Y., 1961) p. 243.

[2] Preliminary Operating Experience with Hough-Powell Device Programs. With H. S. White, T. Aronstein, C. Osborne, N. Webre, and W. G. Moorhead. Nuclear Instruments and Methods 20 (1963) 393-400; North-Holland Publishing Co.

TABLE I

Distribution of 1000 Events Found by Scanner after First HAZE Measurement

(4-prong, 3.5 BeV/c π^+p Events in 72" HBC; ~10% Proton Contamination)

Reconstructed by HAZE-FOG		
π Beam Events	588	
π Non Beam Events	39	
p Events	66	
Ambiguous (Fits ≧ 2 categories)	131	
No kinematic fit	32	
Total events reconstructed		856
Rejected by HAZE-FOG		
Scanner Errors	84	
Film Format Errors	3	
Roadmaker Hardware Errors	3	
FSD Hardware Errors	6	
FOG Rejections	3	
All other, including HAZE-FILTER	45	
Total events rejected		144
		1000

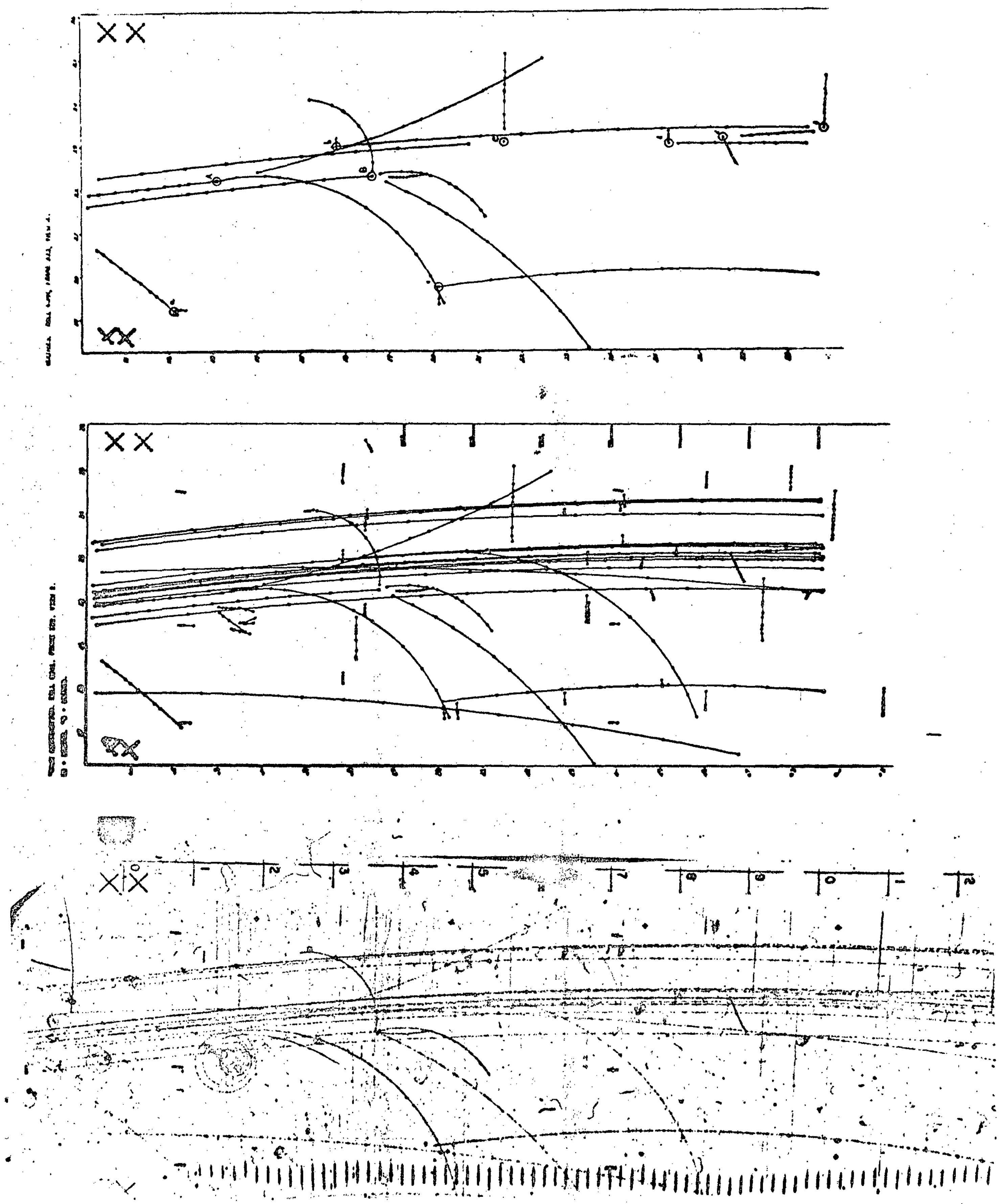

Fig. 1

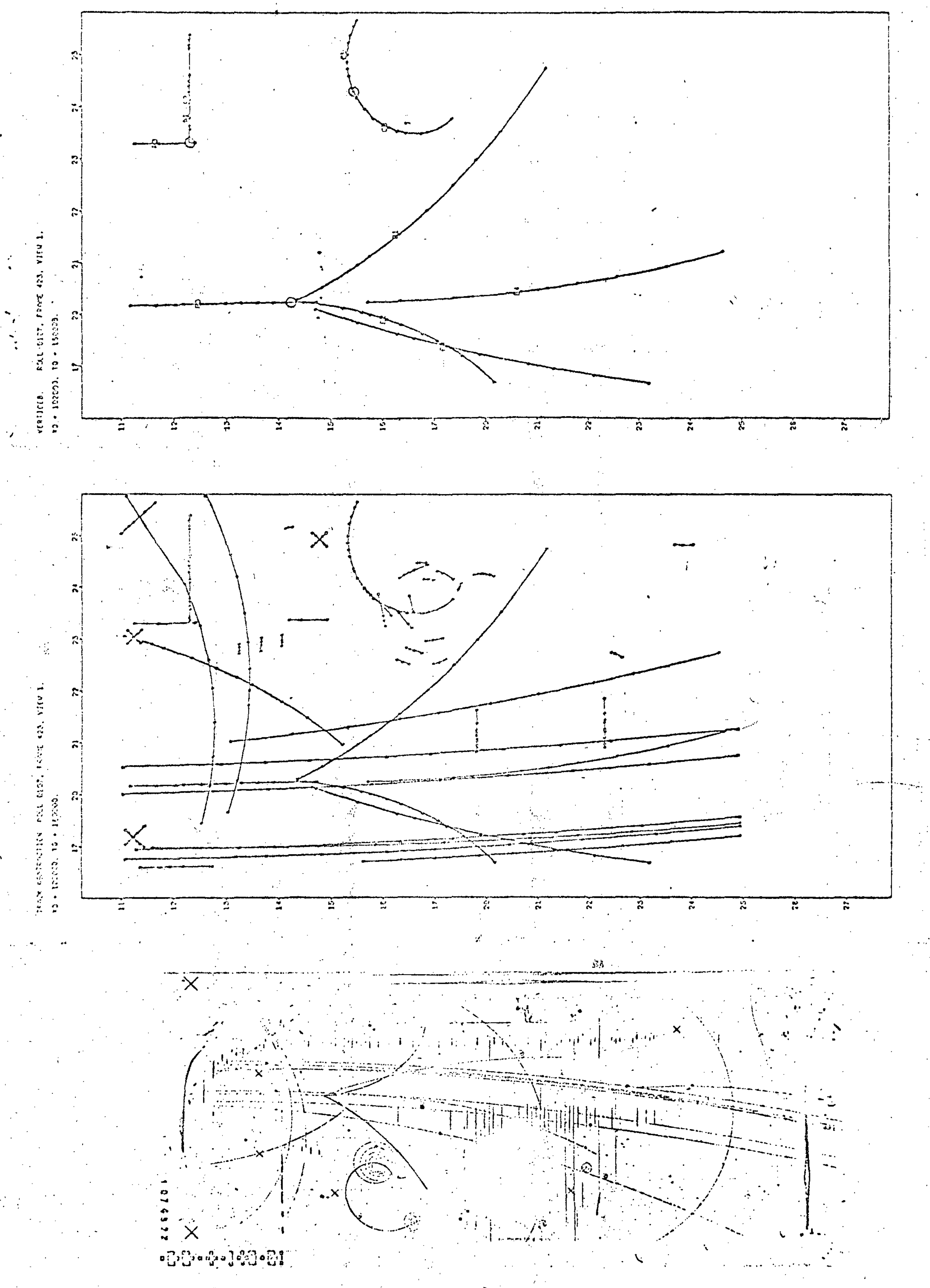

Fig. 2