OXFORD PEPR SYSTEM

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1 INTRODUCTION

The purpose of this paper is to report the performance of our PEPR system in measuring some 13,000 $\pi^- p$ 2 prong events. The exposures were at 690 and 740 Mev/c in the Saclay 80cm chamber.

Working with zone guidance of 4mm x 4 mm on a single view the system measured events at an average of 150 events/hour including on-line operator helping. The pass rate through Match and Geometry was 87%.

Working with the vertex predigitized to 1mm on a single view, and anti-selecting at the scan table events with a confused beam, the current system measures at 400 events/hour without operator assistance. In this mode the pass rate through Match/Geometry was 91%.

2 GENERAL SYSTEMS DESCRIPTION

The flow of information from the scan table to PEPR and hence to Match and Geometry is shown in Fig. 1.

The zone guidance information for about 5,000 events is loaded onto an IBM 2311 disk pack. As PEPR measures the views in succession the view measurement data is merged into the file.

One's knowledge of the vertex position improves as we go from view to view and this is utilised in the event recognition strategy.

The MATCH program developed at Oxford is a vital part of our system. It enables the PEPR automatic measuring software to put out extra tracks in cases of ambiguity, and also it can salvage events with one or more event tracks missing in a single view.

Fig. 2 illustrates the hardware facilities used by the system. If one is running in the 'help' mode an operator can assist the auto system with difficult events via display, lightpen and keyboard.

The current production load runs in 30K including a 4K bank for display storage. It is written entirely in Fortran IV except for the routines for basic scanning and measuring, film transport and displays.

Fig. 3 illustrates the Saclay frame format with the reference fiducials and databox at the left of the image.

3 PEPR SOFTWARE

3.1 General

The first production system for measuring with the current hardware, christened PEPHLP, ran from June 1969 to September 1969. It was developed as a stepping stone toward the goal of an automatic zone guidance system. The event recognition in this system was provided by the operator identifying the vertex and one point on each track of the event. This was accomplished by pointing with a lightpen at a display of data obtained by scanning the 10 x 10 mm region around the vertex with a spot.

As well as providing a basic framework for future development this system checked out the data flow through PEPR from the scan table to Geometry. During its lifetime the system measured 7,000 events at a rate of between 20 and 50 events/hour depending on film quality and the operator.

To step from PEPHLP to the current system, (whose general flow is shown in Fig. 4), the following fundamental developments were made:-

(i) New fast basic scanning and measuring routines

(ii) New fast track follower

(iii) Vertex oriented event recognition strategy

Developments (i) and (ii) were entirely 'home-grown', but development (iii) was based on the proven strategy developed by the POLLY group at Argonne.

3.2 Scanning and Measuring routines

These basic routines utilise the 1mm line element to scan for databox lines, fiducials and tracks, and where appropriate to measure them. Both routines provide software selection of narrow and broad pulses. Currently a pulse is classified as narrow if it is less than 60μ wide at ½ height. Between 60μ and 120μ a pulse is classified as broad. This facility is very important when track following; broad data is treated as 'noise' and appropriate logic is entered.

The operation of the scanning routine SCAN and the measuring routine MSCAN is illustrated in Fig. 5.

SCAN input defines scan co-ordinates (a,b), an angle range m_1 to m_2, and an angle increment n. It scans at the addressed point from m_1 to m_2 every n degrees. The area covered on film is approximately 1mm x 1mm. As data is gathered it is histogrammed into bins 48μ wide by planting the current angle into the bin defined by the data interpolation count. If the bin is already occupied the data is ignored. This technique has given a very fast basic element recognition.

MSCAN is used essentially in the measure mode for fiducials and tracks once SCAN has located the fiducial roughly or located a starting point on a track. The normal mode of operation is to scan at a single angle at the addressed point with gates of ±50μ. It may also be used to measure angle as well as position by scanning through a range of angles, and defining the angle of the data by the centre of the angle range over which hits are obtained.

3.3 Track Following

TRACK is given a starting element (A, B, ϕ) by SCAN and starts tracking with steps of $\frac{1}{2}$mm using linear prediction. When 2mm have been covered it uses a three point circle extrapolation predicting ahead $\frac{1}{4}$ of the current prediction chord. It continues in this mode with the step increasing in size until it reaches an allowable maximum of about 4mm. Then the last 16mm of track are used for the prediction, the 16mm sliding along with the track. Another cut-off for the prediction arc is 10° of track. For curvy tracks this cut-off is reached before the chord length cut-off and the maximum step is equivalent to about 2° of turning angle.

The gates for a scan are computed as a function of the step DL and the prediction arc length L. The minimum gates allowed are ±50μ. MSCAN is called to scan at a single angle with 'narrow' pulse selection.

When either a gap or 'noise' is obtained when tracking it attempts to back-up first closer to the last point. If this is unsuccessful an attempt is made to bridge the confused region by predicting past it up to a maximum step of $\frac{3L}{4}$ where the prediction errors are about ±120μ.

Tracking occurs in three phases - first towards the vertex, then away from it, and finally, if necessary, a retry towards the vertex. On reaching the tentative vertex region an event association check is made by seeing if the track passes through the 'error box' associated with the vertex. If it does not then tracking is terminated.

All tracking is performed in uncorrected deflection co-ordinates. With the current parameter settings for track following this has proved entirely satisfactory. Track follower typically provides about twenty points/track. At the moment these are filtered to ten corrected points. Kink detection is performed on the curve defined by the ten corrected points. The algorithm requires the track to fit a smooth circle. The tolerance is about 20μ for beam tracks but gets much larger for lower momentum. A kink on a beam will usually be detected if the scatter is greater than 1°.

3.4 Some basic measurement times

Typical measurement times for databox, fiducials and tracks are given in Table 1 below.

Table 1

Typical measurement times (for Saclay $\pi^- p$)

Function	Time on PDP6			Estimates for Processor = 2 x PDP6
	Total Time	Hardware Time	% Hardware time Unoverlapped	Total Time
Databox reading	100ms	10ms	100%	55ms
Measure 5 fiducials	150ms	10ms	100%	80ms
Track beam across chamber in 'tentative' mode	70ms	6ms	50%	36ms
Track beam across chamber in 'beam follow' mode	40ms	3ms	100%	21ms
Digitise 30mm of track at 20μ spacing	120ms	35ms	2%	60ms

These times are largely limited by the speed of the PDP6 processor, and thus an improvement of 2 in the speed of the processor would give very nearly a factor of 2 in speed.

The quoted track following times are for following a beam across the Saclay film format, a distance of about 40mm. Following a longer distance, as on the format for the CERN 2 metre chamber costs an extra 0.7ms/mm. However, when dealing with the CERN 2 metre format film, one need only follow about 20mm of track in the event search mode. Once the event has been found the extra length of track can be followed - for a 4 prong this would take an extra 100ms to follow an average of an extra 30mm on each track.

3.5 Event strategy

Tracks are searched for which radiate from a crude vertex (1mm to 2mm on film), and are followed as they are found. The search pattern is a variable number of circles centred on the vertex as shown in figure 6. Through tracks are linked and deleted, and an accurate vertex determination is attempted after each circle is computed. If a good vertex is found with all the correct tracks passing through it, the event is considered measured; if not, the search continues with another circle, or until hope is abandoned. In addition, for the present experiment it was found necessary to initiate an extra beam search at large radii for difficult events. If these efforts fail, at this point an operator may help the system when running in the "HELP" mode.

Since the fundamental principles have been described in talks about POLLY it is not necessary to describe them further here. However, it should be pointed out that the routines had to be considerably developed and modified for the following reasons:

1) The PDP6 computer is slower than the Σ-7

2) The PEPR hardware is <u>much</u> faster than POLLY

3) The PEPR line has useful advantages

Using points 2) and 3) to full advantage has enabled an extremely fast system to be developed in spite of point 1).

3.6 Operator help facilities

These were used in 2 modes for the $\pi^- p$ production.

a) To indicate the vertex with the light-pen on the first view. The operator need only indicate the vertex to an accuracy of better than 1mm. He is presented with a display of the 7 x 7mm area centred on the uncertainty box provided by the scan zone information. This is illustrated in Fig. 7.

The overhead in this operation is about 2 secs/frame.

b) When the automatic event strategy failed to identify the event unambiguously then the operator was given the opportunity to assist the system by a required combination of vertex identification, track addition and track deletion. The operator is given an appropriate message such as 'TWO FEW TRACKS', 'NO BEAM' or 'MEASURE VERTEX'. An example is shown in Fig. 8.

Typical reasons for operator intervention were

(i) Confused beams - in this case the operator makes no attempt to assist since the automatic system has already tried special beam search logic.

(ii) Very weak track due to poor illumination in chamber. In this case the operator tries to identify the track, and an attempt is made to follow the track - if necessary the threshold is dropped to a very low level, up to 5 tries being made at successively lower thresholds.

(iii) Production track goes through very confused region. The operator attempts to select a clear point with the light pen.

(iv) Illegal beam - a check is made for the beam momentum. If this is outside the allowed error limits then the system allows the operator to check the event. In many cases the cause is a 'rogue' beam which also causes problems in succeeding views since in all probability it is outside the normal spread in z of beams. Thus the extrapolation from the 1st view to the 2nd does not reflect the correct error on the vertex position.

(v) Scanner error - an event was passed through with a very short stopping secondary which was impossible to measure with the line. This was outside the terms of reference of PEPR measurement, and so no attempt to help was made.

By far the largest category was (i).

4 PEPR PERFORMANCE

A summary of PEPR measuring performance over a 10,000 event batch is given in Table 2 below.

Table 2

Week 9.2.70 - 13.2.70

Experiment 17 (740 MeV/c, $\pi^- p$ R.D.** Film, 2-prongs)

Elapsed time (Hrs)	PDP6 Time (Hrs)	Lost time* (Hrs)
80	64.6	15.4

*Time-sharing of processor, operator training + breaks, film changing.

Auto events	Helped events	Total events
8,728	1,370	10,098

Total events/PDP6 time : 156 events/hour

Helped events/total events: 13.5%

The history of these events through Match, Geometry and Kinematics is shown in the first entry in Table 3 below

Table 3

Event History

	Fail Match/Geom	Fail Kinematics	Fit Kinematics	Multi-neutral or doubtful
All events	13%	1.5%	78.5%	7%
Selected scan sample	5%	2%	84%	9%

** Reverse developed

Helix fit statistics are shown for PEPR measurements on Fig. 9. They peak at 7μ and have a 1% tail beyond 25μ. All PEPR measurements were done using a 6μ least count.

For comparison a sample of 170 events were measured on a manual machine with a least count of 2μ. The resulting helix fit statistics are shown on Fig. 10. Even with the limited statistics it can be seen that the peak is shifted to 11μ.

The contribution to the helix fit errors purely from Coulomb scattering and uncertainties in the chamber constants has been estimated as about 5 - 6μ.

4.1 Match/Geometry reject reasons

13% of all measured events fail in MATCH or GEOMETRY

	Percentage		
	of all events	of reject events	
1)	2%	15%	Gross failure 1/3 events cannot be found 1/2 too few tracks are found on 2 or more views 1/6 fiducials can not be measured
2)	5.1%	39%	VERTEX LOCATION PROBLEMS 1/3 tracks in some view fail to intersect 2/3 Vertex points in the several views are not corresponding points
3)	3%	23%	FAIL IN MATCH

4) 2% 15% 2 View measurement failures and troubles

1/5 2 view measurement fails MATCH

4/5 poor stereo on some track measured in 2 views

5) .2% 2% Assorted Measurement Failures and Program Shortcomings

(Charge balance failure, no beam track, etc.)

6) .6% 6% GEOMETRY FAILURES

1/3 MATCH passes marginal unassociated track images

2/3 probable Geometry arithmetic troubles

4.2 Performance Summary

A reasonable measure of efficiency of performance by a measuring system is the percentage of all events that have to be reinspected and remeasured after the first measured attempt. At our momentum, less than 1% of all two prongs are from events with two or more neutrals; all the rest are from elastic scatters or single pion production. Thus, to a good approximation, we should expect all events to fit some production hypothesis. We have found that measurements of similar events at close beam momenta with our image plane digitizers have to be repeated between 25% and 30% of the time. In the case of the PEPR measurements, the unsatisfactory results are between 15% and 20%. Thus, PEPR is now, on its first production measurement output a better system than our manual measuring system, even ignoring the superior quality of the PEPR measurements themselves.

5 POST MORTEM DEVELOPMENT AND SYSTEM EVALUATION

A brief study was made of the effects of imposing more severe scanning criteria in selecting our data sample. Three rolls containing 659 events were studied, of which 62 failed in MATCH.

Events were excluded where the event:-

(i) was incorrectly zoned on the scanning list

(ii) did not have the beam track clear by at least 100μ on film for at least 5 mm in at least 2 views

(iii) did not have all production prongs longer than 3mm in all 3 views

(iv) was not the correct topology (e.g. a Dalitz pair or a 4 prong)

This anti-selection reduced the sample to 545 events, a reduction of 17%. Almost all discarded events were for reason (ii).

The performance of the 545 event sample is given as the second entry in Table 3. It was clear that the easiest way to significantly improve our performance was to be slightly more selective in scanning.

5.1 Automatic running with pre-digitised vertex

As a result of our study on our test sample of 659 events we decided to evaluate the performance of the system running completely automatically with the vertex digitised to 1mm accuracy on the first view.

A summary of the criteria for the run and the resulting performance are given in Table 4 below

Table 4

Scan criteria for automatic run on $\pi^- p$ (no operator help)

1 No track image shorter than 3mm in any view

2 Beam must be clear of other beams in at least 2 views (by 100μ for at least 5mm)

Selected Sample (2 rolls) 315 events

PEPR measuring rate 380 events/hour

MATCH pass percentage 91%

Thus this run gave a satisfactory performance through Match + Geometry at a greatly enhanced measuring rate. The percentage of events rejected due to the scan criteria was about 15%, mostly for criteria 2.

5.2 Time Breakdown for Software

A breakdown of time utilisation is given in Table 5 below.

Table 5

Time breakdown for $\pi^- p$

Running with pre-digitised

vertex on one view (to 1mm accuracy)

Activity	% Total time
Film transport	40
Track following	22
Track search + kink detection	17
Databox + fiducials	8
Storing + calibrating track data	4
Various book keeping + I/O	4
Threshold setting	2
Vertex check	2
Track linking	1

Measuring rate: 380 events/hour

with ionisation: ≃340 events/hour

It is obvious from this table that the easiest way to speed up the throughput (from the software point of view!) is to have a faster film transport. For the $\pi^- p$ experiment there was, on average, an event every four frames, the average event-to-event film transport time being 1.2 seconds.

Another way to speed up the measuring rate is to code the vital parts of TRACK in assembly code, while still retaining the logical framework of TRACK in Fortran IV. This will be done in the near future.

5.3 Some 'Wishful Thinking'

It is interesting to predict the measuring performance of the current software + hardware system if it were driven by a computer whose CPU performance is twice that of the PDP6. Another desirable feature would be an event-to-event film transport average time of ½ second, this being accomplished by a faster film transport and an average, say, of 1 event every two frames.

Such an estimate is given in Table 6 below.

Table 6

Measuring System

Current Oxford hardware + software

Computer X ($\equiv$ 2 x PDP6)

Fast film transport

Input

2, 4, 6 prongs pre-digitised to 1mm in one view (vertex only)

-confused beams antiselected

-frequency $\simeq$ one event/2 frames

Performance Estimate

Event recognition and measurement	1.0sec
Ionisation (30mm for 5 tracks)	0.3sec
Film transport time	0.5sec
Average time/frame	1.8sec

Measuring rate = 675 events/hr (?!)

6 CURRENT DEVELOPMENTS AND A FORWARD LOOK

All scanning and measuring for the $\pi^- p$ experiment was performed with the 1mm line element. The basic spot scanning and measuring routine has been written, and is currently being used to gather data for our ionisation algorithms which are in the process of development. It will be also used to find and measure short tracks (less than 1mm) which cannot be found with the 1mm line. The basic spot routine SPOTTY will also be used for measuring end points on tracks, and following very curly tracks which, with the 1mm line, give broad pulses. The lower limit for the 1mm line is about 3mm radius of curvature on films.

The next experiment for our current system is a 3.6 GeV/c $K^- p$ exposure in the CERN 2 metre chamber. Both normal and reverse developed film will be processed, a total of 100,000 events. It is hoped to go into production on this experiment by May.

Once the $K^- p$ experiment is solidly in production development work will begin on developing automatic scanning techniques.

7 ACKNOWLEDGEMENT

We would like to acknowledge the contribution of Dr. C.A. Wilkinson to the system. Dr. Wilkinson implemented our disk handling software, and was responsible for the original versions of the databox and fiducial routines from which the existing routines have developed.

DATA FLOW FOR OXFORD P.E.P.R. GRID GUIDANCE

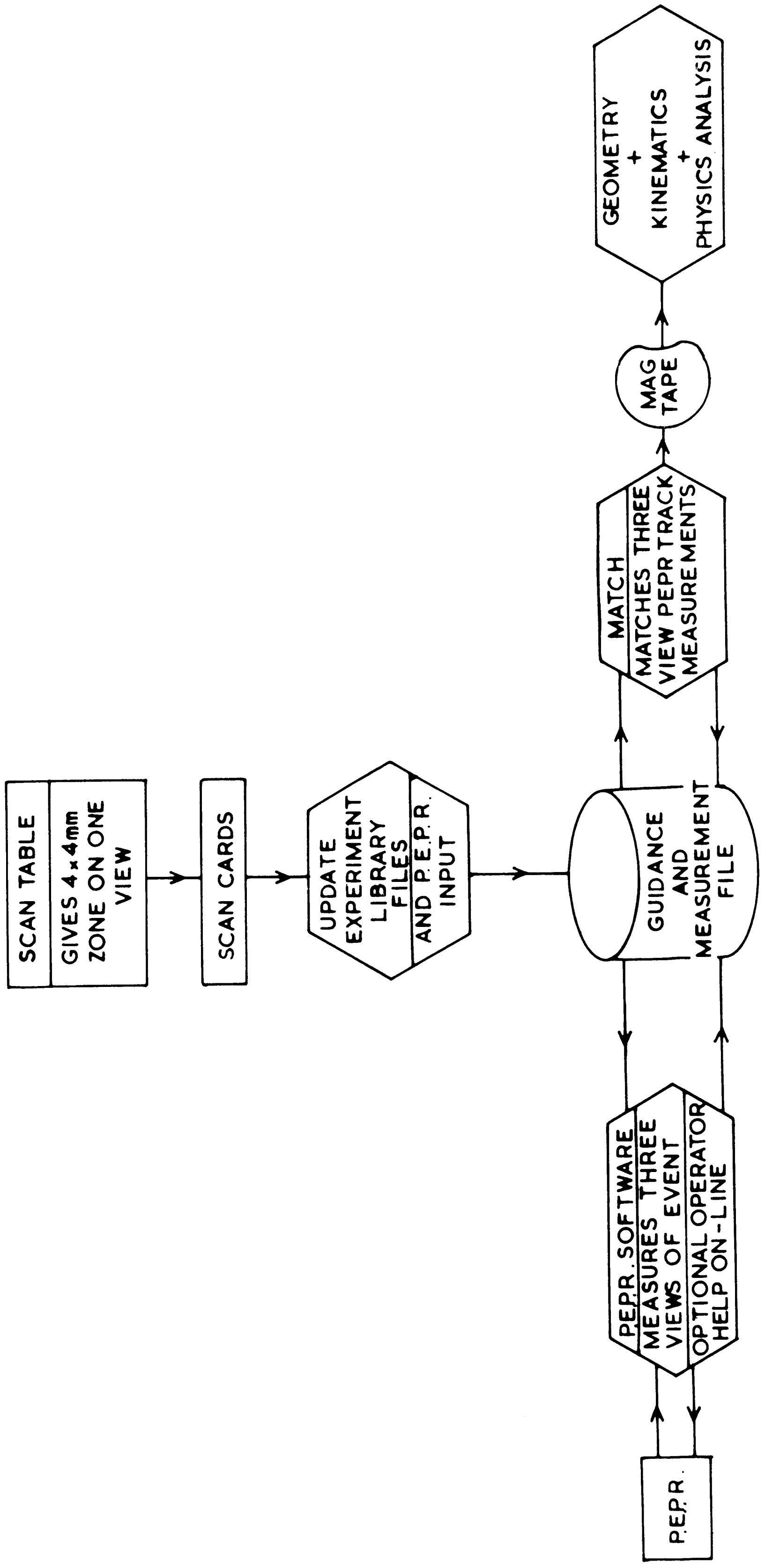


FIG. I

HARDWARE SYSTEM SCHEMATIC

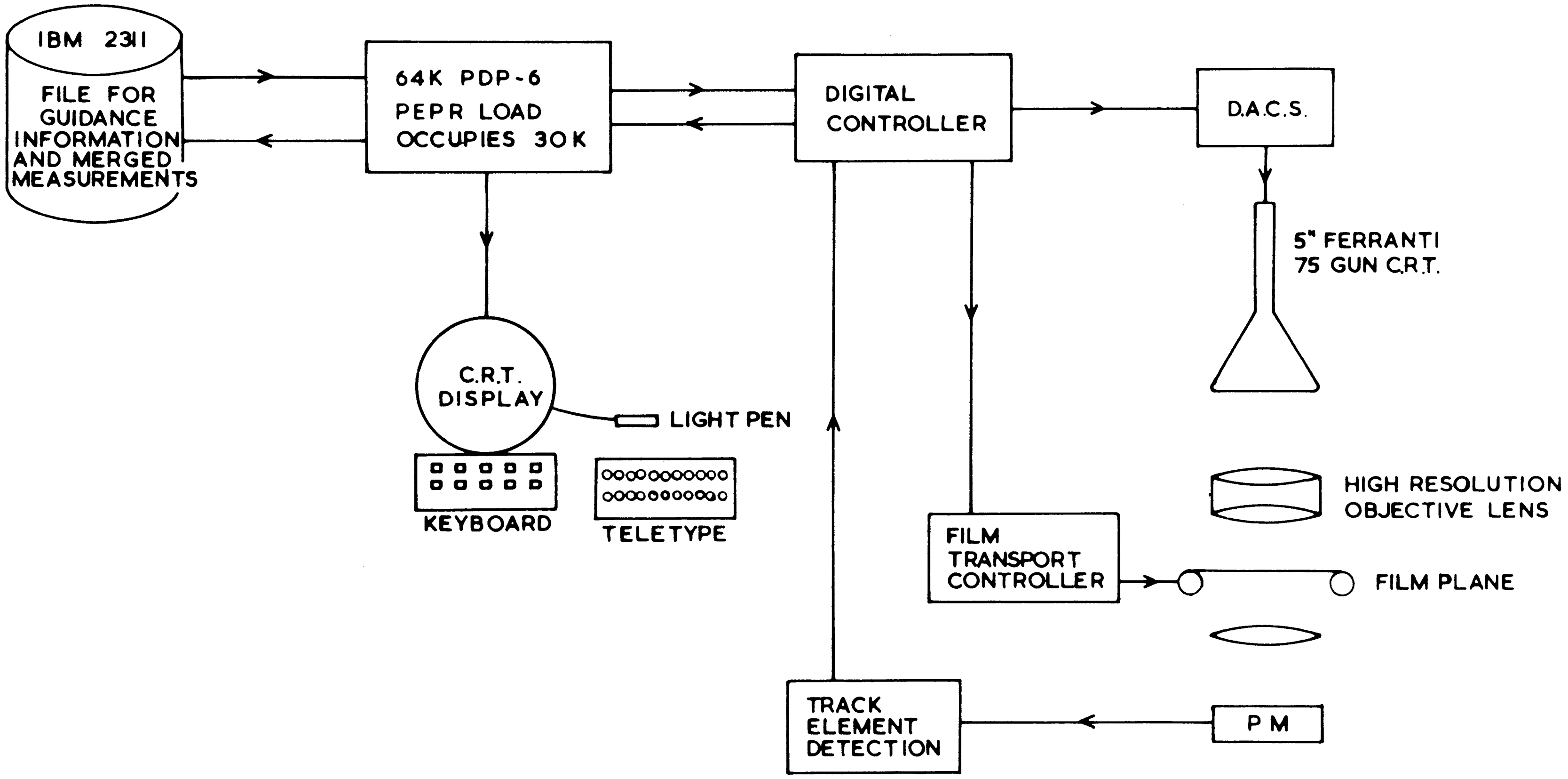


FIG. 2

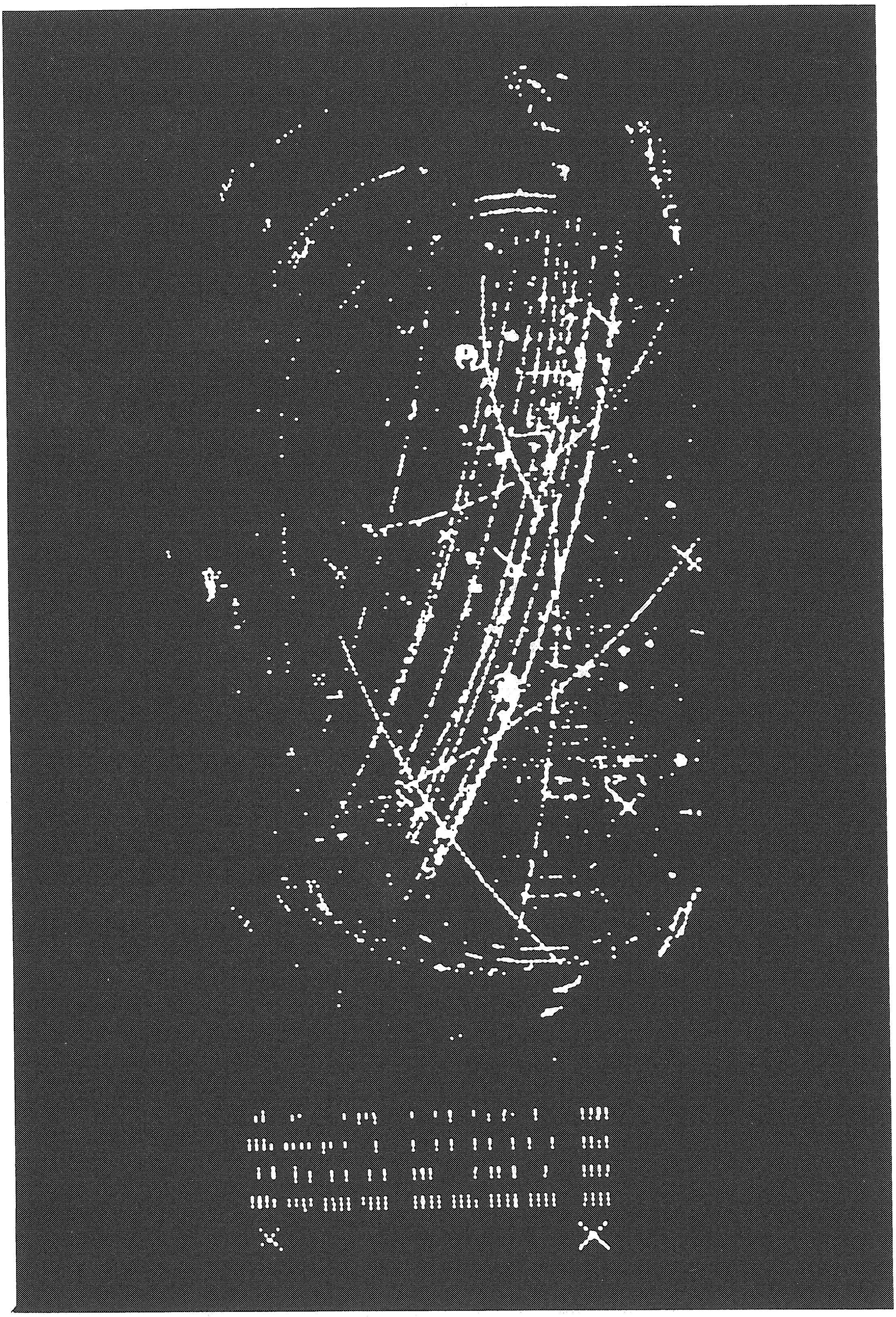


FIG. 3 CRT DISPLAY OF SACLAY FILM FORMAT

OXFORD PEPR

EVENT MEASUREMENT - GENERAL FLOW

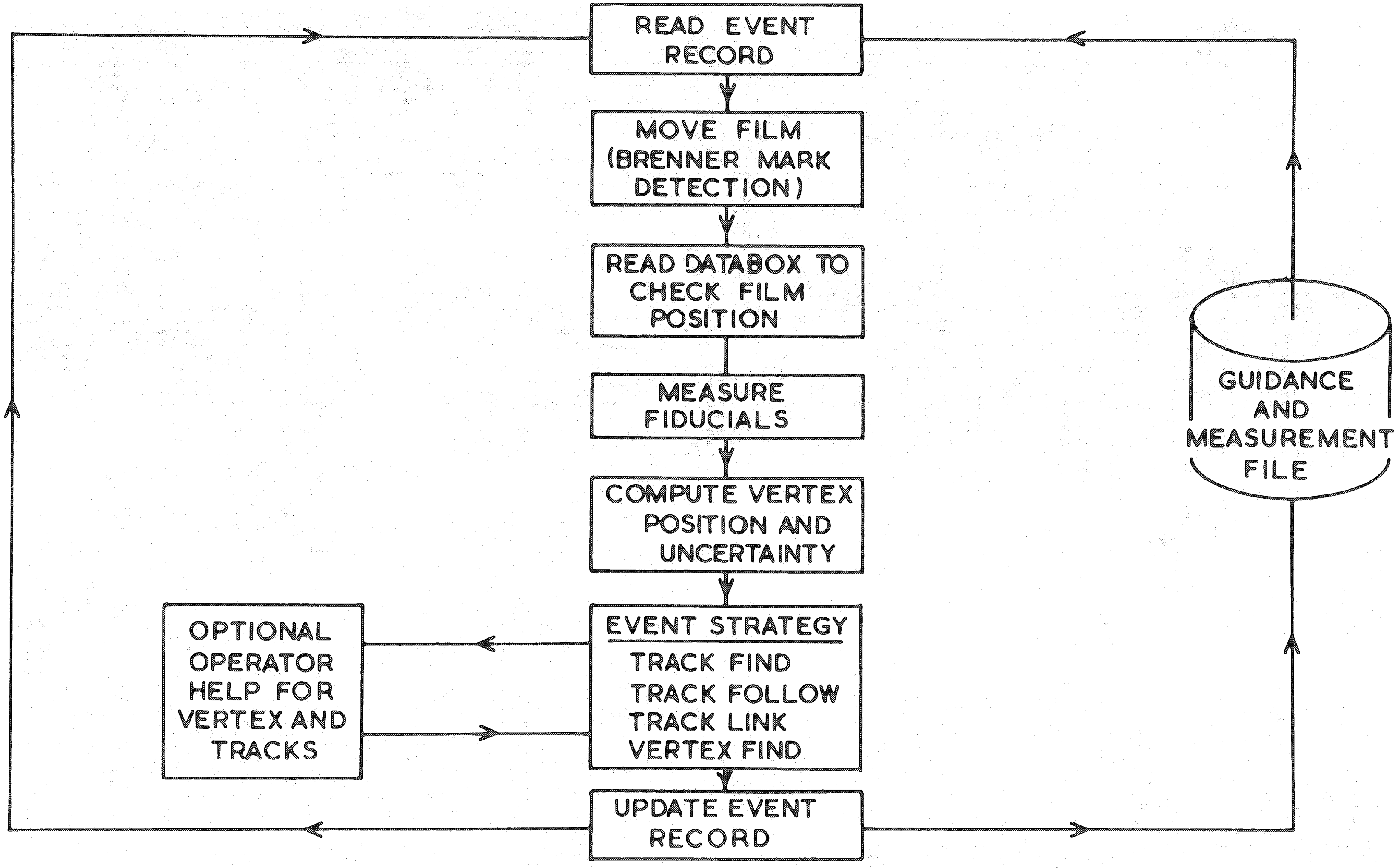


FIG. 4

BASIC SCANNING ROUTINES

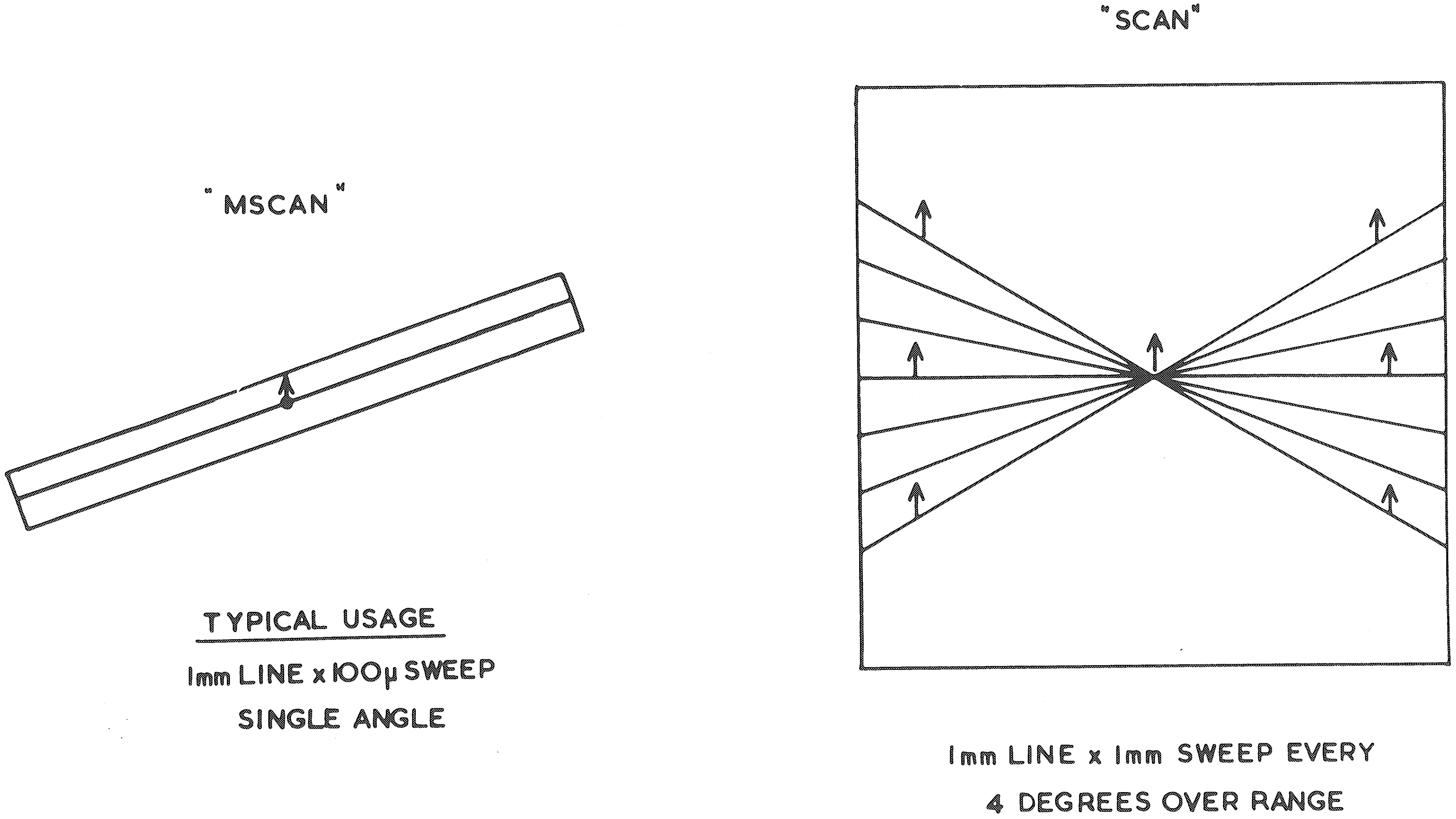


FIG.5 SCAN GEOMETRY FOR BASIC SCAN AND MEASURE ROUTINES

TRACK SEARCH STRATEGY

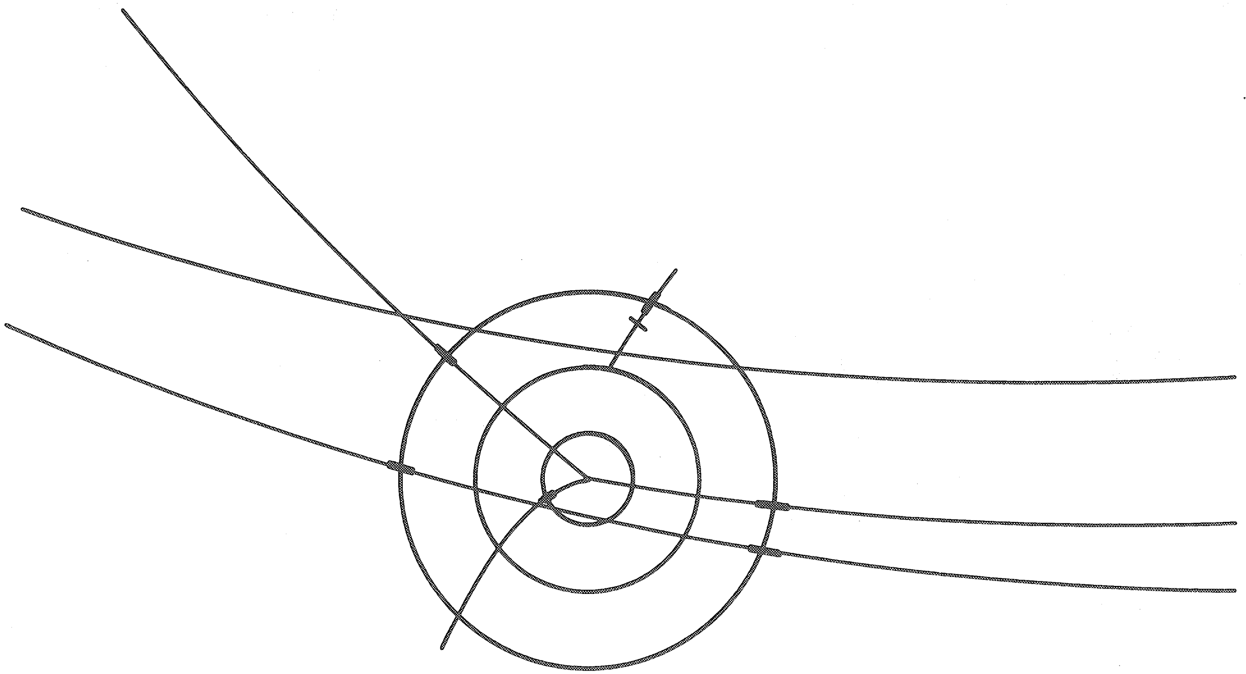


FIG 6 ILLUSTRATION OF SEARCH PATTERN FOR START POINT ON TRACKS

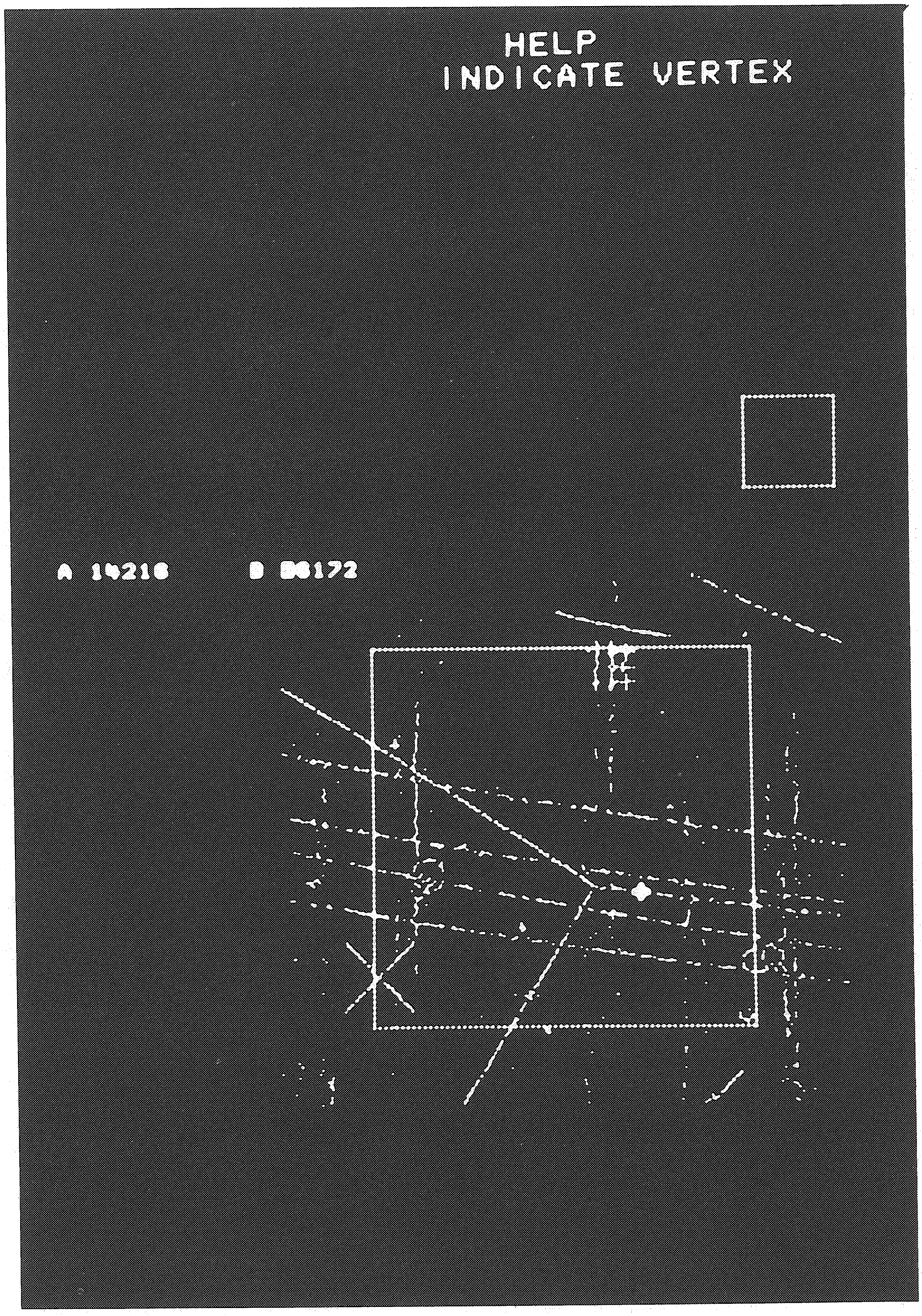


FIG.7 OPERATOR DISPLAY FOR LIGHT-PENNED VERTEX IDENTIFICATION ON FIRST VIEW

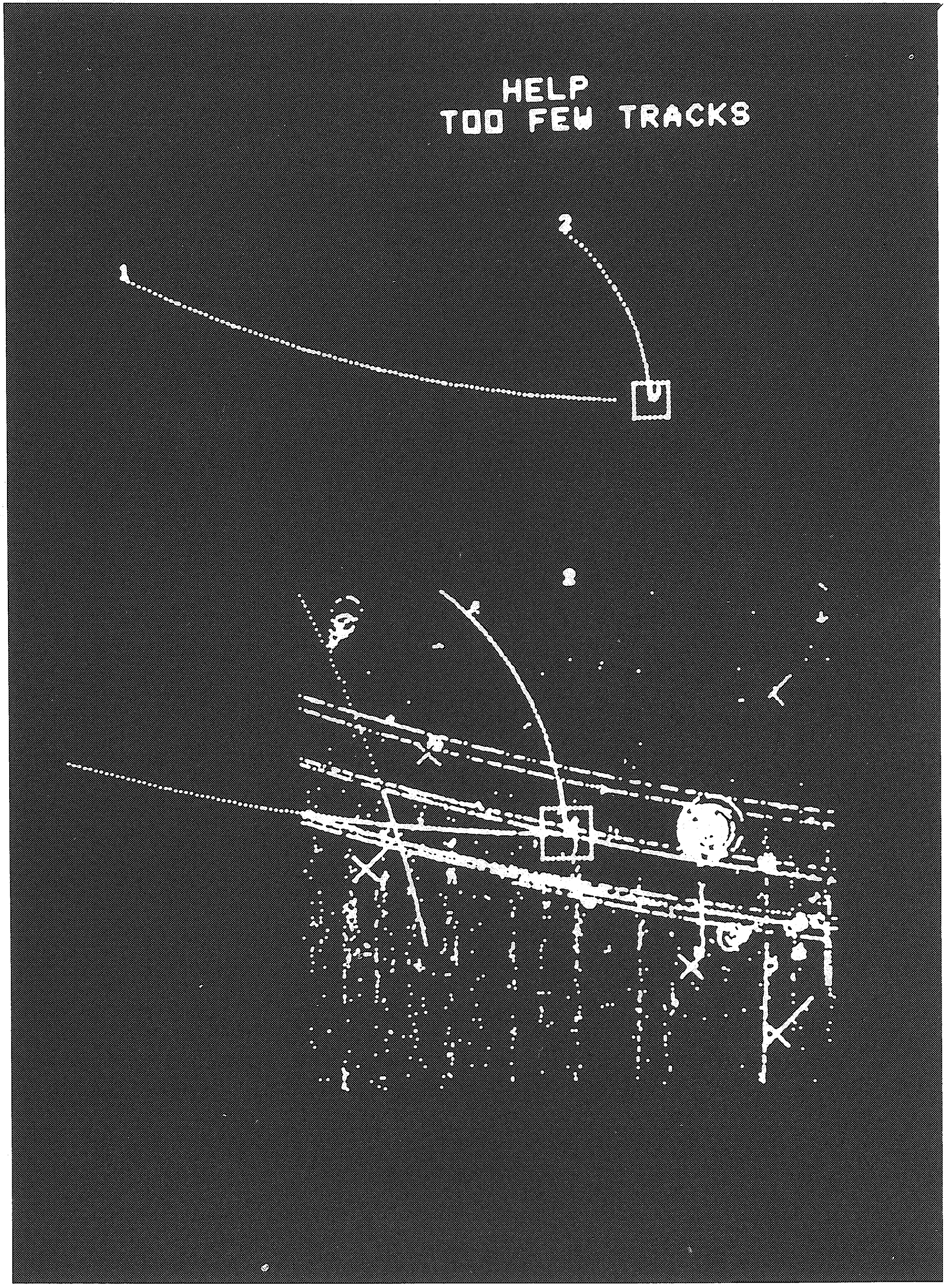
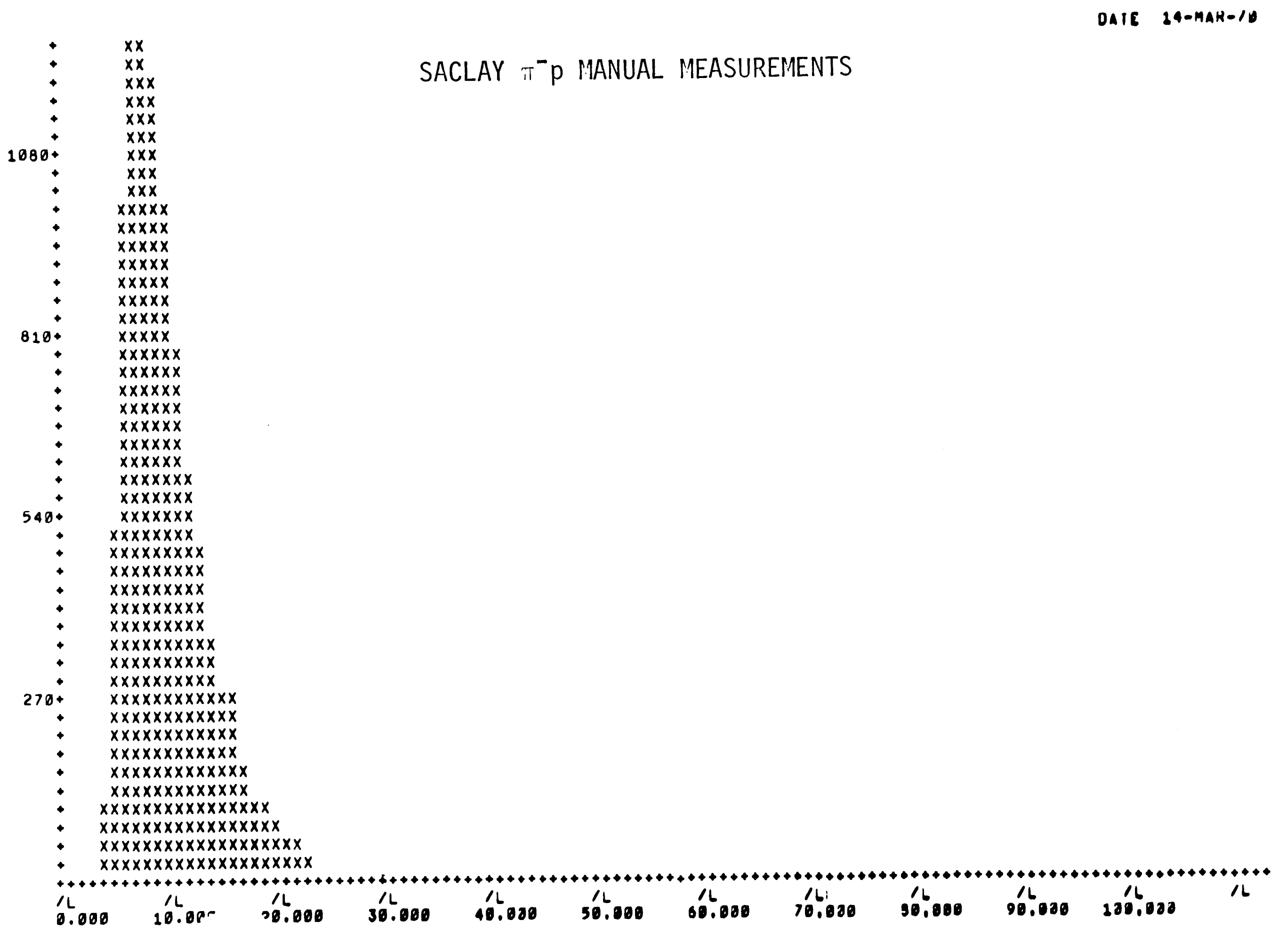


FIG. 8 TYPICAL OPERATOR DISPLAY FOR FAILED AUTO EVENT



```
          11111
        15022108653221111
        11254810205887110754222111
       5280379890398497018403606677787488561345 234542121   121 1 1 111  21  2   21   111     11  2    2
THE PLOT CONTAINS 10135 EVENTS,X= 27 EVENTS, IMAX=  46,    0 EVENTS OUTSIDE PLOT                P-CODE  1/ 1

  HELIX FIT STATISTICS
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FIG.9 HELIX FITS WITH PEPR MEASUREMENTS

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                                                                                  DATE  16-MAR-70
                              SACLAY π⁻p PEPR MEASUREMENTS
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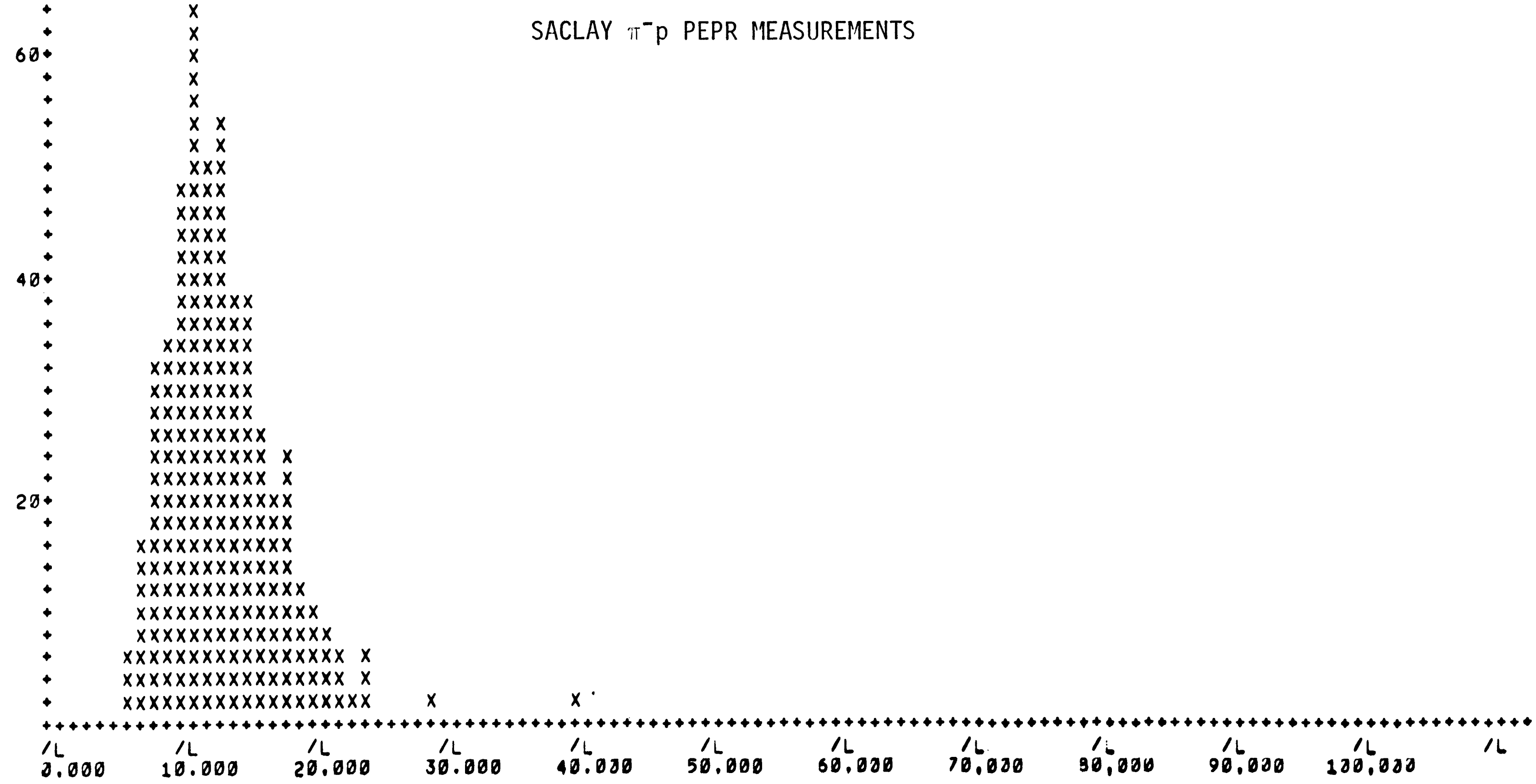

```
      13346553322211
     167358514987042096261  12 1  1 1 1 2  1                        1
HE PLOT CONTAINS   515 EVENTS,X=  2 EVENTS, IMAX=  32,    0 EVENTS OUTSIDE PLOT              P-CODE  1/ 1

  HELIX FIT STATISTICS
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FIG. 10 HELIX FITS WITH MANUAL MEASUREMENTS (2μ LEAST COUNT)

DISCUSSION

R. BÖCK *(CERN):* Your measurement rate is computer limited, and your CP efficiency is about 50%. Would the idle time be sufficient to run TRACK MATCH (or more geometry) concurrently?

J.F. HARRIS: At the moment the system is not finalized. With a little work we can probably get the PEPR program down to 27 K -- at present we have a lot of debugging features in, also single step features for the operator. We think we can get the MATCH program down to about 25-26 K. Then we will have MATCH running asynchronously with PEPR in real time, not necessarily on measurements just done, but on measurements done a few days ago. The 50% of CP time that we have will be just enough to do track matching for four prongs; for two prongs there is plenty of time.

L. KOWARSKI *(CERN):* Do your rates of 380 or 700 events/hour include the grid positioning of the vertex?

J.F. HARRIS: The film is prescanned, and the vertex is given to 1½ mm accuracy on just one view. The prescanning is of course a limitation.

R. BROWN *(Illinois):* How do the various costs in an experiment apportion, including the pre-digitization and post-analysis?

P. DAVEY: The cost per event through PEPR, including amortizing the computer, is 21 cents. The prescanning, including the capital cost of scan tables amortized over six years, and the salaries of operators, costs about 12 cents per event. (No figure was given for post-analysis.)

W. SLATER *(UCLA):* What topologies were involved in your rate of 400 events/hour?

J.F. HARRIS: Two prongs, nothing else. We thought at the beginning that this would be easier from the point of view of the number of tracks. But from the point of view of pattern recognition it turns out to be rather difficult because there are a lot of pseudo-two-prongs. We do not think that going to four prongs will make a significant different to the rate. On average, on a typical frame there are about 20 entries to the track follower, so a four prong means only two more entries to the track follower, and we are limited by film transport times anyway. So it is probably less than a 1% effect.

W. SLATER *(UCLA)*: Have you made any headway towards automatic scanning?

J.F. HARRIS: Concerning automatic scanning, we will start that this summer, after we have got the K^-p experiment (including ionization) into production. Of course the performance depends on film quality, particularly the beam tracks, which are the problem in automatic scanning, at least with the POLLY strategy. It is not clear how blessed we shall be with the film from the CERN 2 m chamber.

D. HOLTHUIZEN *(Amsterdam)*: What did you use to connect a new roll of film to the leader to get such a fast roll change?

J.F. HARRIS: Sellotape.

R.T. Van der WALLE *(Nijmegen)*: All your rates are for measurements that do not include ionization measurements. Could you comment on what will happen to your rates if you do perform ionization measurements?

J.F. HARRIS: We have not yet finalized this, and it depends on how many millimetres of track we measure for ionization and at what spacing. I estimated for the PDP-6 that if we measure 30 mm of track at 20 μ spacing, that is 1500 digitizings per track, it takes 100 milli-seconds. So if we are digitizing five tracks, the time would be 3½ seconds, instead of 3 seconds, a 15% effect.

D. LORD *(CERN)*: Until now you seem to be avoiding the problems of confused beam tracks; can you continue to do so if you do automatic scanning.

J.F. HARRIS: It is a question of physics philosophy. The one successful automatic scanning group in the world is POLLY, and one of the main reasons for their success (apart from the fact they had clever people working on it) was that they had good film. I do not know how long we can avoid the problem of confused beam tracks -- I have no experience of it in automatic scanning.