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On Getting Results from an HPD System*

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ABSTRACT

Evidence is presented to show that HPD measurements at CERN have reached equality with and now surpass CERN hand data in reliability. Perhaps the most direct and incisive test for correct measurement is provided by a three-view geometry diagnostic; its use for the study of performance of this (and any) analysis system is described. Various other problems connected with the development and use of the HPD system are discussed briefly.

I. Introduction

Just 4 years ago this month a rather primitive but still recognizable HPD converted a bubble chamber picture into some 20,000 high precision numbers and stored the picture in this form in the core memory of the IBM 709 computer at CERN and subsequently on magnetic tape. A plot of the numbers from one of the first pictures, made on the relatively low resolution display oscilloscope supplied by IBM, is shown in Fig. 1.

It seemed reasonable to us at the time that the great number of precision measurements of bubble image positions, performed in not so very many seconds, would be useful for high energy physics. Consequently considerable effort was devoted by many people at Berkeley, Brookhaven and CERN to creating production measuring machines. These machines were designed to operate under computer control, and to digitize at rates up to 400 frames per hour. About 2 years ago this basic task was accomplished at all three laboratories. Fig. 2 shows one of two FSD's at BNL.

Difficulties were then encountered. While no single difficulty seemed especially fundamental, the occurrence of scores of trivial difficulties suggested that perhaps the complexity of imitating human behavior by computer programs was the real difficulty—and one possibly not to be overcome with reasonable effort and in a reasonable time. It can be reported now that this is not the case. Recent HPD measurements at CERN have been shown to equal and surpass the CERN hand

data in reliability, i.e. in all parameters so far devised to describe the confidence with which the measurements may be used for physics. Owing to local variations in the large and rather inflexible HPD program systems, other installations may achieve this desirable condition later rather than sooner and in other ways, but simple, objective tests of the correctness of measurement now exist and we urge all users and generators of HPD measurements to insist on application of these tests and revision of the basic measuring computer program until the sign of the difference in quality between HPD measurements and local hand measurements is clearly positive. Beyond this crossover point, the existence of a computer on line makes possible a distinct further improvement in quality and it may be hoped that some groups will pursue this line of development.

II. Problems, Mostly Solved

A. The Forgotten Order of Magnitude

A 4-prong event normally requires the correct measurement of 5 tracks each in at least two views. In fact, current best practice demands measurement of each track in three views so that even a 2-prong event requires correct measurement of 9 track images.

However, the developer of any measuring system will naturally focus his attention on the measurement of a single track image and will begin to feel satisfied when (say) 49 out of 50 track images are measured perfectly. Since, however, these 50 track

images comprise only about 5 events, and since our supposed badly measured track image is quite likely to spoil one event, the instrumenter's satisfaction at a 2% track-image error rate is premature, corresponding as it does to a 20% event error rate.

The ~ 10 track-image measurements per event measurement I call the "forgotten order of magnitude". It is of course no longer forgotten by any of us with 10,000 event measurements performed.

B. Hardware

It is possible to suggest that an HPD, or PEPR, or SMP, is just another tape unit and a read-only one at that. However, speaking for the HPD from experience, and for any other device by extrapolation, the greatest care and highest engineering standards are required to produce a useful instrument. It is impossible here to discuss the array of elegant solutions to specific hardware problems, but I will list two hardware problems which still cause distinct annoyance in some of the best families:

- 1). Picture number read and film registry on stopping.
The HPD must handle in practice an outrageous variation of film quality.
- 2). Dust in the spot generator or at the film platen.

An outstanding unsolved problem for CERN and BNL, who use bubble density information regularly, is maintenance of constant sensitivity

for digitizing bubble images from one view to the next of a given roll of film, especially when the successive views are not measured on the same computer shift.

C. Road Guidance

Current HPD systems use a pre-digitizing process at the scan table for guidance of the computer in its selection of coordinates corresponding to the desired event from the totality of coordinates supplied by the HPD. Fig. 3 shows a road maker mounted on a standard BNL scan table. In a "tight-guidance" system 3 points are predigitized on each track, as well as two 'X' fiducial marks, in each view. The precision of predigitizing used by the various groups ranges from 20-60 microns (referred to the film). Road widths on film are typically 400 microns.

It is everyone's experience when starting an experiment using new film, a new chamber, new scan tables, or a new HPD, that the roads overlay the tracks very badly indeed. In Brookhaven experience, work on the relation between scan table and HPD coordinate systems leads fairly quickly to a state where only about 1 track image in 100 leaves its road at some point. However, in addition a few percent of the frames show no tracks at all in the roads, either in one view or in all three views. The empty-roads failure is usually due to a wrong picture either at the scan table or at the HPD, but may on occasion be due to an error in predigitizing fiducials or in finding fiducials at the HPD. The one-track-in-100 failure will lead by itself to 10% event

failure, but can be dealt with fairly economically by a re-run procedure to be described later.

It should be pointed out that the achievement of even the current marginally adequate road fit depends on a transformation from scan-table coordinate system to HPD coordinate system which pins the two systems at two fiducials which span the picture. In the CERN system the two-point pinning is accomplished individually for each picture; at BNL it is accomplished on the average as the measuring run proceeds. The techniques for and defects in each system are left for private discussion.

Computer checking of predigitizer data, which is done by a program called MIST, is extremely important, as shown by the flood of errors turned up when breaking in either a new scanner or a new scan table. This checking could and perhaps should be done by a very small on-line computer which could then also record the checked data from many scan tables on magnetic tape. A 3 view reconstruction of roads into "tunnels" would detect most digitizing errors and also provide more accurate roads in each view. The Columbia group have adopted this procedure.

D. The HPD Coordinate System

An advantage of the HPD over PEPR is the nearly absolute coordinate system which can be provided, but nevertheless there are more free parameters than in conventional measuring projectors. In particular the value in microns of a least count in the flying spot direction must be determined for both the normal and orthogonal scans, either by reference to a precision grid or to the moiré-fringe gratings which measure the stage position.

Although the flying spot coordinate is determined by reference to a grating, and so is determined digitally, the relative magnification of the lenses which image the flying spot on the grating and on the bubble chamber negative is not known a priori with high precision.

Until recently all HPD installations had to determine and put up with a static non-orthogonality between flying spot axes and the perpendicular axes determined by the stage motions. However, in the Mark II HPD design of R.B. Palmer, available commercially from Sogenique, this static tilt may be removed in both scans. We have found the elimination of these two parameters so convenient that (with some trouble) we have also accomplished their removal on our earlier Mark I. There remains of course a small and easily calculable dynamic tilt owing to the simultaneous motion of stage and flying spot.

Quite recently we have discovered that the film plane and flying spot grating planes must be very accurately perpendicular to their respective optic axes, to avoid significant variation in the value of the flying spot least count over the area of the negative. Again, we leave this point for private discussion by the experts.

The displacement of the origin of the orthogonal scan from that of the normal scan is usually measured by digitizing a single bubble image in both scans. Alternatively, fiducials may be found also in the abnormal scan.

In sum, then, there are a total of either 2 or 4 constants to be measured in setting up the HPD coordinate system.

III. The FILTER Problem

A properly functioning set of scan tables and HPD provide a reasonable digital replica of the bubble image content of roads $\sim 400\mu$ wide centered on each track. In a given road there may be as many as 2000 bubble coordinates, of standard deviation $3-8\mu$ depending on the angle of the tracks involved relative to the flying spot direction. Usually 95% of the coordinates belong to the track desired, the remainder belonging to δ -rays, dust, and crossing tracks. Occasionally there is significant competition over a reasonable fraction of the road-length from a parallel track or a small-angle crossing track. Quite rarely, the road is genuinely complex. Short roads offer special problems because the angle of a correct track relative to the road edge can be larger, and because there may be only a dozen or so digitizings on the track. For long tracks of particles with momentum ≤ 500 MeV/c, there will be considerable change in curvature along the track, which, relative to a circular road-edge, yields an S-curve. Flares, coat hangers, joints between chamber illumination regions, etc. can introduce into the road extensive regions with no digitizations at all. Given two close tracks, the track encountered first by the flying spot will shadow the second when the centers of the two tracks are separated by a distance δ . Depending on the design of the track center circuit δ varies between 30μ and 80μ .

The problem presented to the FILTER program is to select digitizings lying on the track of interest, and only on this track, to average the selected digitizings in groups of typically

10-50 to provide about 20 output points of 1-3 μ precision, and finally to calculate a number uniquely related to the bubble density of the track. Of these tasks only the first is particularly difficult. Even here the difficulty arises largely because of the great variety of situations which occur, rather than the difficulty of dealing with any one.

The original FILTER program, designed by H.S. White of Berkeley in collaboration with Brookhaven and CERN, has been used to measure 10,000 events at Brookhaven and many tens of thousands of events at Berkeley. Speaking of Brookhaven experience now, despite attempts to control the FILTER output via computer checks of smoothness, last fall definite indication of a substantial mistake rate was obtained. It was then shown, with the aid of a 3-view geometry diagnostic, that 20-25% of events which would have been accepted for physics contained at least one track with a measurement error distinctly outside the ensemble described by the usual error matrix. The geometry diagnostic showed moreover that the FILTER error consisted usually of attaching one or a number of average points spoiled by digitizings from crossing or nearby tracks to a set of correct points. Occasionally a wholly wrong track was measured in one view. We will call these errors FILTER "mistakes". Actually, about half the events contained FILTER mistakes, but in only the 20-25% mentioned was the effect large compared to the total external measurement error including Coulomb scattering.

It was in January that one accepted defeat at Brookhaven in efforts to make the first FILTER program do the job. Only minor changes in FILTER were reported in progress at Berkeley, and

rather distinct modifications were considered necessary. (Howard White advises us now that the changes over the past nine months, while adiabatic, have been quite substantial and he will tell us about them.) CERN had made a fresh attack on FILTER, in collaboration with the Rutherford Laboratory, beginning over 18 months ago but was not quite able to show a high percentage of correctly measured events as of January. After study of the other new attacks on FILTER, viz. that of the Collège de France in Paris, and especially the very interesting and ingenious program of the Columbia group, it was decided to implement at Brookhaven a particular set of ideas developed there by Nardi, Strand, Stonehill, Crennell and Hough. At each of a number of design decision points this group chose systematically what they conceived to be the most powerful alternative. Their program is mostly coded, about half debugged and will be carried at least far enough so that a decision based on performance can be made between it and the others, especially the CERN and Columbia programs. It is conceivable then that within a few months any HPD installation will have a choice among several satisfactory FILTER programs.

The CERN program will be described in a paper later in this session by one of its chief designers, Moorhead. It has produced data which have passed all of an extensive battery of tests, including the 3-view geometry diagnostic which exposed the deficiencies in Brookhaven data. Evidence is presented below showing that the data are superior to the CERN hand measurements, thus qualifying according to the criterion proposed at the beginning of this talk.

The FILTER programs are of great interest to specialists, but of general interest only when they are shown to work. So we will leave this part of the discussion to Moorhead and go on to the results so far obtained at Brookhaven and CERN. We will rely on Howard White to report on results at Berkeley.

IV. Results at Brookhaven and CERN

A. BNL Expt. 18

At Brookhaven a group of 5 or 6 physicists, led by D.L. Stonehill, have taken 300,000 pictures in the 20" hydrogen bubble chamber, with 3.5 BeV/c π^- incident (Expt. 18). The energy chosen was the highest available in this particular beam. Although the intention was and is to study, with high statistics, such questions as the angular distribution of the decay of the neutral dipion system, the group did not mind the existence of a good many published results on resonance physics with similar beams, since they wished to develop confidence in the system. The pictures contain about 50,000 2-prong events, 15,000 4-prong events, and in few thousand strange particle events. The group has pre-digitized about 30,000 events and last fall measured about 7500 2-prong and 2500 4-prong events in a measurement run of 5 weeks. They used about 30 hrs of 7094 computer time per week and so averaged about 70 events/hr. At that time on-line manual repair operations were used on 5-10% of the tracks. Since then this technique, which had as its aim a single pass measurement procedure which would reject less than 5% of the events, has been transferred off-line, where it works better and costs less. What fraction of the peak rate of ~ 160 events/hr will be obtained now is not known because processing has not yet resumed. At the scan tables

events were scanned for and predigitized at the rate of 12 events/hr. or 1000 events/week/table-used-2-shifts. The scan-table time may be divided into (i) event-finding and (ii) predigitizing time; one finds that the latter process goes at about 25 events/hr. for 2-prongs and about 15 events/hr. for 4-prongs. Since scanning time per event varies strongly with the frequency of events and complexity of the pictures, while predigitizing time per event appears to be just a linear function of the number of tracks in the event, this separation of functions is useful for predicting rates in an arbitrary experiment.

Even with on-line repair of individual tracks, about 12% of the events were incomplete; therefore a hand measuring projector was used to fill in the 1% or so of track images still unmeasured. Following this pass, about 95% of the events were reconstructed successfully by the FOG 2-view geometry program. The failure rate at this point was not zero largely because of purely procedural problems. This general remeasure procedure seems to be a good one, and it is planned to keep using it at Brookhaven.

The suggestion of serious measurement mistake rate which was mentioned earlier occurred next, when we found that 7% of the events were "non-physics" events. By a non-physics event is meant one that fits no event type among the set of event types known to occur (including types with more than one neutral) or one that fits a particular event type which however the bubble density measurement definitely excludes. (We had by this time tested the bubble density measurements of the HPD sufficiently that we could rule out a mistake in the bubble density measurement for the great majority of this second class of non-physics event.) In most of

the non-physics events a secondary track is measured with too high a momentum so that the missing energy and missing mass are negative. It is clear then that something like an equal number of secondaries can be expected to be mis-measured with too low a momentum; in this case we would not see the error because the event would be classified with the multiple-neutral events. This situation is quite general: in most high-energy bubble chamber experiments error detection at the kinematic-fitting stage is very incomplete. Taft and Willis have both emphasized this point; the geometrical measurements should be checked by geometrical tests, and the physics results should follow "open loop".

At this point we decided on theoretical grounds that a 3-view geometrical reconstruction program should be an excellent error detector, since even a smooth error in measuring any one view of a track should not escape the teeth in the redundancy afforded by the third view. This has proved to be the case. We were fortunate that D.J. Crennell and K.M. Derrick at Brookhaven were well acquainted with one such program, the Harwell program, HGEOM. HGEOM works, as do the two other 3-view programs THRESH and TVGP, by constructing a trial helix in space, projecting the helix back onto the 3 film planes and varying the helix parameters until the sum of the squares of the deviations of the measured points from the helix projection is a minimum. HGEOM and TVGP correct the helix for ionization loss, while in the CERN system the correction is made later in GRIND. In Fig. 4 we plot a set of minimum deviations, at 3μ resolution on the printer, i.e. 6μ between the ruled lines. The abscissa is angle of turn around the helix, so the deviations in the 3 views are correlated. This track has about 2μ rms error averaged over 3 views and represents standard

performance when FILTER functioned correctly. FILTER mistakes show up as a hook on the end of a deviation plot in one view, or as two points splayed on either side of the track by $10\text{--}30\mu$, or by a large-sagitta parabola in one view, indicating an incorrect track chosen by FILTER in that view, and in various other ways. These mistakes can be detected by a computer diagnostic as well as by eye, but one must be aware of several effects which are not measurement errors but which can confuse the diagnostic.

Fig. 5 shows one such effect. Here the measurements are correct, but the different views are slightly incompatible. For this case it is now known that the incompatibility arises from imperfect knowledge of camera positions at the chamber; if one rotates the camera plate by a few mils relative to the chamber window, the incompatibility disappears. In other cases incompatibility arises from errors in fiducial measurements.

Fig. 6 shows a second effect. Here is a kink in a track of momentum about $1\text{ BeV}/c$. The change in angle is about a milliradian, and cannot be found at the scan table even when one knows where to look for it. These residuals are from CERN HPD data, using THRESH. In this case the slight change in sagitta may mean a decay. Note that the rms error of 4.5μ quoted by THRESH would be considered acceptable, and that if the kink is in fact a scatter it is included in the Coulomb scattering contribution to the usual error matrix. However, these kinks may confuse a diagnostic program operating at the micron level, and can also give trouble to a FILTER program.

Fig. 7 shows an example of incompatibility of views in CERN data. Note that the THRESH rms error of 7μ is almost all due to

this effect, and the HPD track measuring error is only about 3μ . We have found in practice that if the HGEOM σ is less than about 4μ , the track is surely measured correctly, if $4 \leq \sigma \leq 15\mu$ it may be either correct or incorrect, and if $\sigma \geq 15\mu$ it is almost surely measured incorrectly.

As a final point before leaving the deviation plots, Fig. 8 shows THRESH deviations for a 200 MeV/c pion which turns through about 80° . The change in radius of curvature of the track relative to THRESH's constant-radius helix is somewhat alarming, but in fact is probably of no consequence in view of the enormous sagitta and appreciable Coulomb scattering error this track. It does mean that my rule for interpreting HGEOM σ 's is not correct for THRESH, since this correctly-measured track has a THRESH σ of 34μ .

Having learned these things about the "normal" performance of a 3-view program, one is in a position to study the residual plots for FILTER mistakes. Taking a sample of ~ 1250 tracks from ~ 350 events, the Brookhaven group found that in about 50% of the events some one of the ~ 12 track-image measurements per event continued a FILTER mistake. However on comparing HPD and hand measurements for these events, only 20-25% contained "mistakes which matter", i.e. errors in momentum and angles distinctly outside the statistical ensemble described by the error matrix. Speaking loosely, a FILTER error in a short high-momentum track matters, and in a long, low-momentum track it does not; at low enough momentum even the road coordinates are of sufficient accuracy.

Finally, it was clear from a study of the deviation plots from hand measuring machines (which at BNL use track-centering servoes) that the HPD measurements were distinctly worse, so the experiment was halted for a reprite of FILTER.

B. Results at CERN

At CERN, the first HPD bubble chamber experiment consists in the measurement of 4-prong events from 5.7 BeV/c $\bar{p}$ in the 81cm hydrogen chamber. The total number of events in the sample is 20,000, of which 17,000 have been pre-digitized, and 10,000 measured by the HPD. On the first pass, 21% of the events were rejected by the overall system, and on re-rough digitizing and remeasuring, 50% of the rejects are accepted, leaving a two-pass rejection ratio of 11%. The 11% will be sampled by hand measuring machines until the nature of any biases is established.

The beam track is not measured at CERN but, in both momentum and angles, average values for the beam are used. About 1200 events are measured per week, at an average rate of about 40 events/hr. This is the slow HPD designed for use with the IBM 709. The CERN Mark II HPD will be available in a few months.

As with Brookhaven data, the first information about undetected errors in the accepted sample came with "non-physics" events. The CERN definition of non-physics is again either (i) negative missing mass for every fit tried or (ii) bubble density grossly incompatible with all acceptable kinematic fits. At CERN the bubble density was judged by eye at the scan table for every event, as well as measured by the machine. Event-types with K-pairs

were not tried. Also there may be some π^- contamination in the antiproton beam. These last two circumstances mean there will be some legitimate non-physics events. In a sample of 7000 events there appeared 1.6% non-physics events. Hand measurements confirm the HPD measurements in 2/3 of the cases, so candidates for HPD mistakes amount to 0.5% of the input sample. The 1/2% here may be compared with the 15x larger 7% at Brookhaven.

Next we compare the χ^2 -distribution for 4c and 1c fits with those from duplicate measurements by the hand measuring projectors (I.E.P.'s). Figs. 9 and 10 show the 4c distributions, and Figs. 11 and 12 the 1c distributions. There is no statistically clear difference, the sample being limited so far by the unavailability of quantity hand data. The Brookhaven machine χ^2 -distributions are not much different, although there are slight tails, and this points up a limitation in this test. To the extent that measurement errors are catastrophic they will simply remove events from the sample, and not disturb the χ^2 -distribution of the events remaining. So the test is to some extent a comparison of hand vs. machine measurement for well-measured events. In an earlier larger sample of CERN HPD-I.E.P. χ^2 comparisons (not on an event-by-event basis), the distributions showed a 10-20% smaller measurement error for the HPD.

A more convincing test is the 3-view geometry test on deviations, which at CERN was performed using THRESH. Tracks of momentum >600 MeV/c only were used, to remove from consideration the effects of energy loss. Deviation plots for the first few dozen tracks showed that the end-point generated by FILTER were

unsatisfactory, owing at one end to an unjustified extrapolation procedure and at the other end to the use of a single FSD digitizing instead of an average point. These end points have been dropped. Of the measured average points only 1 in the first few thousand looked at had a deviation which was inconsistent with a Gaussian distribution of a few microns rms error. This point was 20μ off the track and is not understood, being considered inconsistent with the logic of CERN FILTER by the CERN programmers.

This first study of THRESH deviations has now been extended, and in particular the first track by track comparison with the I.E.P.'s has been made. The comparison is based so far on only about 200 high-momentum tracks each. In order to make the comparison objective, the possibility of kinks and incompatible views is ignored and a track is classified as "bad" if 2 or more points show THRESH deviations greater than 16μ , and "good" if 1 or 0 points do. The first result is that 5% of the HPD tracks are classified as "bad" whereas 15% of the I.E.P. tracks are "bad". (An unknown and certainly large fraction of the 5% are kinks or view-discrepancies, so this comparison can be made more incisive.) For those tracks classified as "good", the two distributions of the THRESH deviations, normalized to the same number of points, are shown in Fig. 13. The rms errors, 4.3μ and 6.5μ , include the systematic effects mentioned. Fig. 14 compares the normalized distributions for tracks classified as bad. These curves are not interpretable more closely without knowledge of the systematic effects, but the sign of the difference is satisfactory.

C. Bubble Density

Bubble density measurement with the HPD is a separate topic too extensive for proper discussion here, but a few points may be mentioned.

At both CERN and Brookhaven difficulty has been encountered in obtaining essentially 100% digitization of dense tracks, but at Brookhaven the problems have been largely overcome.

The most natural variable for expression of HPD measured bubble density is $\ln \frac{T}{M}$, where T is the total number of scan lines crossing a track and M is the number of "misses", i.e. the number of scan lines for which no digitizings on the track are recorded. (For tracks of small dip and perpendicular to the scan line $\ln \frac{T}{M} \propto \frac{1}{\beta^2}$.) However, for dense tracks M is a small non-negative integer, so $\ln \frac{T}{M}$ is singular and has exceedingly asymmetric errors. The bubble-density fit to a event is therefore better carried out using the variable $\frac{M}{T}$ directly.

It is important to check the compatibility of bubble density measurements for the three views of each track before accepting any. Among other things, this procedure helps to guard against a variety of peculiar optical phenomena, such as the "ghost track", for which the human measurer checks automatically.

At Brookhaven, HPD bubble density measurement is somewhat better than visual inspection at the scan table, though not as good as hand gap counting. At CERN, partly owing to lower quality film in the first experiment, the bubble density measurement techniques are not so well developed.

D. Physics Results

Finally, we report some physics data from the CERN anti-proton experiment which are tests of machine performance. In Fig. 15 are shown the distributions of p and $\bar{p}$ momentum in the center of mass system for the reaction $\bar{p}p \rightarrow \bar{p}p\pi^+\pi^-$. If the strong interactions are charge independent the two distributions should be identical, and within statistics they are. However, the antiprotons have a laboratory momentum distribution largely between 3 and 5 BeV/c, while the proton laboratory distribution is largely below 1 BeV/c. (The individual p and $\bar{p}$ momenta in the cm system are known to be uncorrelated.) Any HPD bias in the measurement of a momentum distribution would be expected to be different for the two curves. It follows that there is no evidence for any HPD bias.

Clearly, such arguments are quite indirect and integral, showing how un-incisive physics tests are as measurement tests. However, the tests had better be passed.

Fig. 16 compares HPD and hand measurements of the effective mass distribution of $p\pi^+ + \bar{p}\pi^-$ for the final state $\bar{p}p\pi^+\pi^-$. The HPD distributions is normalized to the number of hand events.

V. Future Developments

At both CERN and Brookhaven the immediate task is the application of current techniques to a wide range of experiments, using film from a number of different bubble chambers. Nevertheless, certain developments, particularly in programming, would be very welcome.

It would be very desirable to reduce the amount of predigitizing at the scan table. The CERN filter program may be most adaptable for this development, since it uses road guidance only at the beginning of each track. The method would require predigitizing the primary vertex, plus any vertex not connected by a charged track with the primary vertex, plus the end point of any track when that end point will be encountered before the vertex in the course of normal or orthogonal scan of the HPD.

At Brookhaven the computer scanning programs of Marr and Rabinowitz are being used experimentally in an effort to measure the elastic scattering cross section for 7 BeV/c antiprotons in the range of scattering angle $1/2^{\circ}$ - 3° . The problem is an interesting application of machine scanning in that such small-angle scatters cannot be detected reliably by human scanners.

Rough estimates suggest that general computer scanning with HPD input can compete economically with human scanning when computers of the class of the CDC 6800 are available, i.e. in about two years. Whether the technical problems can be solved satisfactorily by that time seems more doubtful.

The most welcome hardware development would be simplification of the equipment. If laser beams can be deflected electrically or piezo-electrically, the precision stage and spinning disk of the present HPD's may be replaceable by a somewhat simpler element. A laser beam should permit scanning speeds limited only by the data processing rates of the very fast

computers now becoming available; it should also permit a 5μ spot size, which may be appropriate for the images of very large bubble chambers on 70mm film. With or without lasers. service functions connected with the operation of flying spot digitizers should be transferred as completely as possible to the associated computer.

Figure Captions

1. A low-resolution CRT plot of coordinates measured by the prototype HPD.
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15. A comparison of cm momentum distributions for p and $\bar{p}$ in the reaction $\bar{p}p \rightarrow \bar{p}p\pi^+\pi^-$. The identity, within statistics, of the distributions is evidence against HPD biases (see text).
16. $p\pi^+ + \bar{p}\pi^-$ effective mass distributions; comparison of hand and machine results, normalized to the same total number of events.

FIGURE 1

FIGURE 2

FIGURE 3

Figure 5

$R=129$
 $L=36$
 $DIP=.19$
 $\sigma=4.5$

Figure 6

$R=220$
 $l_1=28$
 $DIP=.07$
 $\sigma=7.1$

Figure 7

Figure 8

Figure 9

χ^2 IEP

5.7 GeV/c ANTIPROTONS
4-PRONGS
 χ^2 IEP v.s. χ^2 HPD

4C - FITS

48 EVENTS

Figure 10

EVENTS
PER 0.2

EVENTS
PER 0.2

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Events/20 Mev
Normalised to 479 total

Figure 16