EXPERIENCE WITH THE CERN HAZE PROGRAM

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In this paper I present some of the results we have obtained at CERN from the measurements of bubble chamber photographs on the HPD. The people who have contributed to the various aspects of the analysis of the results are: A. Accensi, Mme V. Alles-Borelli, B. French, A. Frisk, H. Hannerfeld, W. Krischer, A. Meyer, L. Michejda, W.G. Moorhead, B.W. Powell, P. Seyboth and J. Seyerlein. Before presenting any numerical results I will first indicate what the main developments of the CERN HAZE program have been since last year's conference in Paris.

a) A new version of FILTER has been written, which now employs the basic philosophy of track following.

b) A routine has been written to deal separately with the beginning part of the track - the idea being to clear up any bad master points, which FILTER might have produced in this region. This routine is also designed to deal with short tracks and cases where FILTER produces too few master points. Elsewhere in this paper this routine will be referred to as the HH routine, the initials being those of the author of the routine, Harold Hannerfeld.

c) A diagnostic program has been written which produces a print-out of what is happening in FILTER, and it also indicates where all the digitizings are relative to the road edge.

The part of HAZE which deals with the abnormal scan was not properly tested until 8 weeks ago, when we had the first run of the HPD for bubble chamber pictures in the Abnormal Scan Mode. The bugs produced were easily dispensed with, and we have had a fully working program for the last 6 weeks. During these 6 weeks we have measured just over 500 events of the

5.7 GeV/c anti-proton experiment.

The events measured were nearly all 4-prong events. The beam is $\bar{p}$ at a momentum of 5.7 GeV/c and the chamber used was the Saclay 80 cm hydrogen bubble chamber. The interactions studied are anti-proton plus proton combining to produce a combination of protons, anti-protons and positive and negative pions, sometimes together with one or two neutral particles i.e.:

$$\bar{p} + p \longrightarrow (\pi^+ \pi^- p \bar{p}) + (\pi^0 n \bar{n})$$

These are various aspects of the results which we need to look at, such as success of the HPD measurements, comparison of results obtained from IEP and HPD measurements, etc, and the results have therefore been divided into three basic sections.

1. Taking only events measured on the HPD, we have made a breakdown of all the events and also all the tracks into either a success category or various failure categories.

2. A sample of events (68) have been taken which were measured both on the HPD and the IEP, and various comparisons between the results have been made.

3. A small sample of events were measured a few times on both the IEP and the HPD. From an analysis of the results for these repeated measurements, one can investigate the consistency of the HPD and IEP measurements, and also estimate the measurement errors in both cases.

1. Analysis Sequence of HPD Events

The path of an event which is to be measured on the HPD is given in Fig. 1. First the event is measured roughly on the MILADY scan-table; the scan-cards produced are then read by the program MIST, which checks the cards for any obvious inconsistencies. The output of MIST is a magnetic tape (the scan-tape), which is used to tell the HAZE program which frames to select for measuring on the HPD and also whereabouts the event is within the frame. The track and fiducial measurements found by HAZE are then passed, via magnetic tape, into the program THRESH for the geometrical reconstruction of the tracks in space, and from there the event is passed into the program GRIND for the kinematic analysis. What happens beyond GRIND does not concern us in this paper.

Of the 500 events measured on the HPD, 157 have been analysed in detail after obtaining the THRESH results. Apart from the printed geometry results, we have also had the help of two very useful diagnostic outputs; the HAZE diagnostic which has already been mentioned and a plot of the measurements on the CALCOMP plotter of all tracks which either failed to converge in THRESH or had too large an error on the fitted radius (greater than 8%).

a) <u>Analysis of tracks</u>

A breakdown of the fate of all the tracks in the 157 events is made in Table 1. It has been found necessary to separate the tracks into two categories, beam and non-beam, because the results for beam tracks are much poorer than for the other tracks. The main reason for this difference is that there are many beam tracks on the film, usually very close together, and it is extremely difficult for FILTER to separate them. A further difficulty is introduced by the fact that, for this experiment, the operating conditions of the chamber were deliberately set to produce a fairly low ionization level (in order to make the job of measuring the ionization with with the HPD easier), and thus many of the tracks, including beam tracks, tend to be quite weak.

The first column in Table 1 gives the total number of tracks and the second column gives the number of tracks which were reconstructed successfully. The criteria for success was (1) complete convergence in the least squares fitting procedure in THRESH and (2) the errors on the geometrical parameters all had to be small (less than 5%). A track which did not meet these success criteria was counted to have failed. The remaining columns in Table 1 distinguish between the various reasons for a track failing.

S The track failed because of an error on the scan tape. This column therefore includes all errors due to the scan table, the scan table operator and the MIST program.

F The track failed because the FILTER routine in HAZE gave some wrong points.

H The track failed because of faults in the HH routine. This column includes two types of errors, (1) where the HH routine found wrong points, even though all the FILTER points were good and (2) where the HH routine failed to remove a bad first point on the track, though it was clear from the digitizings available, that it should have done so easily.

W The track has too few digitizings. This causes two possible results, either (1) FILTER finds no points because the track is indistinguishable from the background, or (2) another track, which is strongly digitized lies within the same search area (the road), and FILTER follows this wrong track. This latter case has only been found to occur with beam tracks. It is worth adding here that in the majority of the "W" cases, it was impossible from looking at the digitizings within the road, to tell even by eye that the correct track existed.

T The track failed because of an error in THRESH.

N The track failed, but it was impossible to give the reason why; i.e. the measurements looked perfect and there were no ambiguities in FILTER, but the geometry results were poor.

B The track failed because of bad tape. These few cases exist because for these events HAZE was reading the digitizings from tape (i.e. off-line), and sometimes a bad patch of tape would cause a read redundancy, which meant that one view would be lost for an event. The tracks included in this column are those which absolutely needed the missing view for their reconstruction

Classification of Tracks

	TOTAL NUMBER	OK	S	F	H	W	T	N	B
BEAM	157	106	9	20	2	12	6	2	0
NON-BEAM	638	557	45	16	10	2	2	3	3

Table 1

From the figures in Table 1 we arrive at the following conclusions. (All percentages quoted are a percentage of the total number of tracks measured.)

Success rate

BEAMS = 67.5%   NON-BEAMS = 87%

HAZE errors

BEAM	FILTER accounted for 13%	}	21.5%
	HH " " 1%		
	TOO WEAK " " 7.5%		
NON BEAM	FILTER accounted for 2.5%	}	4.5%
	HH " " 1.5%		
	TOO WEAK " " 0.5%		

Notes (1) The errors caused by the HH routine are certainly bugs in the program, and it is hoped that they will all be cleared up soon.

(2) Of the 16 non-beam tracks which failed for reasons of FILTER, it is known definitely that 4 of these were caused entirely by a program mistake, which caused FILTER to reject the track,

even though the points were perfectly alright. Therefore to assess the success rate of the FILTER routine as it is at the present time, we should really subtract out these four cases from the failure list. The revised figure for non-beam tracks thus becomes

Reject Rate due to FILTER = 1.9%

This figure corresponds to about 0.7% per view.

Scan errors

Reject Rate for all tracks = 7%

Errors due to the MILADY hardware = 3%
Errors due to the MILADY operator = 3%
Errors due to the MIST program = 1%

Note : The main error made by the scan table operators is mixing up two tracks on one of the views: for example tracks 4 and 5 will be measured correctly on views 1 and 2, but on the third view, track 5 is measured as track 4 and vice-versa.

b) Analysis of events

In Table 2 a breakdown of the events is made similar to that which we made for the tracks in Table 1. The first column in Table 2 gives the total number of events and the second column gives the number of events which were successfully reconstructed. An event was considered satisfactory if each of the individual tracks belonging to the event was well reconstructed, and also the vertex was reconstructed without large errors. In the version of THRESH used for the HPD, the vertex is reconstructed by extrapolating back along the tracks belonging to the vertex and finding the best "point of intersection" of the tracks. The third column in Table 2 contains the number of events which were successful except for the beam track; i.e. all tracks except the beam track were well reconstructed, and the vertex had small errors. Now in the particular experiment which we are measuring on the HPD, the properties of the beam tracks are known extremely well, and hence it is not necessary that the beam be well measured, for the event to produce a useful kinematic result. In the GRIND program, the parameters of the beam track may be input into the program as data and these values will overwrite the values found by THRESH. Therefore one may expect the events given in column 3 to be as useful for the kinematic analysis as those in column 2. An event is considered to have failed if one of the non-beam tracks failed in THRESH, and these events are allocated to one of the remaining columns in Table 2. The meaning of these columns is the same as for Table 1, with the exception that all the HAZE failures are now collected together into one column headed HAZE.

Classification of Events

TOTAL NUMBER	OK	OK without beam	S	HAZE	T	N	B
157	85	33	16	16	2	2	3

Table 2

The numbers in Table 2 provide us with the following success and failure rates.

Success rate (with the beam included) = 54%
Success rate (with the beam not counted) = 75%
Events rejected because of HAZE errors = 10%
Events rejected because of SCAN errors = 10%

2. Comparison between IEP and HPD results

A sample of 68 four-prong events were measured on both the IEP and the HPD.

a) Badly measured tracks

In GRIND various tests are made on the results coming from THRESH and error flags are set if the geometry results are poor. A generally accepted criteria is that if the GRIND error number for a track is greater or equal to 100 then the track is considered to be "badly measured" and the event will probably be sent back for remeasuring. Without giving any details (these can be found in the GRIND Manual[1]), this means roughly that a "badly measured" track is one which either did not converge in THRESH or else the error on the radius was too large. A comparison between the failure rates for non-beam tracks yield the following figures.

Total number of tracks considered	=	272
Percentage badly measured on IEP	=	11%
Percentage badly measured on HPD	=	9%

Only 4% of the tracks were badly measured on both the IEP and the HPD.

b) Errors from THRESH

THRESH makes a least squares helix fit for each track and it is useful to compare the size of the errors found for the track parameters. These parameters are the radius ρ, the dip angle λ and the azimuthal angle ϕ. We have normalized the THRESH errors by dividing them by the errors used in GRIND. The GRIND errors are true external errors. They indicate what the expected measurement errors are and they are quite independent of any fitting process. The formulae used to compute these external errors can be found in the GRIND manual[1].

Comparison of THRESH errors

	HPD	IEP	IEP/HPD
MEAN of $\Delta(1/\rho)_T/\Delta(1/\rho)_G$	0.43	0.56	0.77
MEAN of $\Delta\lambda_T/\Delta\lambda_G$	0.90	1.14	0.79
MEAN of $\Delta\phi_T/\Delta\phi_G$	0.51	0.70	0.73
MEAN of $\Delta P/P$	0.85%	1.04%	0.82

Table 3

The suffix T means THRESH and the suffix G means GRIND.

In Table 3 the mean values of the normalised THRESH errors are given for the three geometrical parameters for both the IEP and the HPD measurements. Only non-beam tracks, which were not "badly measured" were used to compute these means. The fourth row of Table 3 contains a similar assessment of the average measurement error found on the momentum P; i.e. the mean of $\Delta(\frac{1}{\rho})_T / \frac{1}{\rho} \simeq \frac{\Delta P}{P}$ is computed for both the IEP and HPD measurements. The figures in column 3 are the ratio of the figures in the first two columns and they give a positive indication that the HPD measurements are indeed more accurate than those of the IEP.

c) Successful events and values of χ^2

We define a "good event" as an event in which all non-beam tracks are well measured.

Total number of events measured	=	68		
Number of "good events" from IEP measurements	=	48	=	70%
Number of "good events" from HPD measurements	=	51	=	75%

The number of these good events which were common to both the IEP and the HPD was 40. The kinematic hypotheses tried in GRIND for this experiment were either one-constraint fits (with one neutral particle) or four-constraint fits (with no neutral). Considering only the 40 common "good events", it was found that every four-constraint fit found with the IEP measurements corresponded to a four-constraint fit with the HPD, and the same was also true for one-constraint fits and the cases which produced NO Fits, except for just one event which gave a one-constraint fit for the IEP and a NO Fit for the HPD.

It was easy to confirm that the four-constraint fits were identical in every case, but because of many ambiguities in the cases of one-constraint fits, together with a shortage of time, we have not yet confirmed that the same is true for all the one-constraint fits.

In Fig. 2 a comparison is made of the χ^2 values found for all the four-constraint fit events measured in both IEP and HPD. There are 14 events altogether, but in fact they do not all belong to our sample of 68 events. Some other results did exist for four-constraint fit events and to make the sample for Fig. 2 as large as possible we have included all available events. For each event a point is plotted on the graph in Fig. 2, the x co-ordinate being the χ^2 value found with the HPD measurements and the y co-ordinate being the χ^2 value found with the IEP measurements. The average value of χ^2 is 4.5 for the IEP measurements and 3.7 for the HPD measurements, but the scatter diagram in Fig. 2 is much more informative than these averages.

3. Repeated Measurements

In order to determine the relative consistencies of the IEP and HPD measurements, repeated measurements of the same event were made on both the IEP and the HPD. The sample size was six events and each event was measured six times, making 36 events in all. (A new scan tape was made each time for the HPD events.) Unfortunately not all the events were reconstructed successfully and the final tally of good events was rather less than the number we had at the beginning.

One of the events measured on the HPD, consistently on all measurements, had wrong points on two of its tracks due to the HH routine, and it was finally decided to reject this event altogether from the analysis. The remaining 30 events were not entirely free of operator errors, and for this reason two events were lost from both the IEP and the HPD samples. After obtaining the GRIND results for the 28 good events left, three tracks from both the IEP and the HPD events were found to fail the "well measured" criteria and these tracks have also been excluded from our analysis. Though this reduction in our sample size obviously reduces the reliability of any conclusions we might make, the sample is still large enough to provide useful results. Nevertheless it is agreed that a bigger sample would be more desirable and it is intended to repeat the investigations in the near future on a larger scale.

a) Comparison of external errors

Our first investigation was to try to assess the external measurement errors on the geometrical parameters $\frac{1}{\rho}$, λ and ϕ. In section 2 we made a comparison of the internal errors given by THRESH. For both the IEP and HPD events the following computations were made.

1) For each track we compute the mean of $\frac{1}{\rho}$, λ and ϕ from the results obtained from the six different measurements.

2) Now using these means we compute the values of $\dfrac{\overline{(\frac{1}{\rho})} - \frac{1}{\rho_i}}{\Delta(\frac{1}{\rho_i})}$ for each track. $\Delta(\frac{1}{\rho_i})$ is the GRIND external error and we use it here again as a normalising factor.

3) The distribution of $\left\{\overline{(\frac{1}{\rho})} - \frac{1}{\rho_i}\right\} \Big/ \Delta(\frac{1}{\rho_i})$ for all tracks of all events is considered as a whole and the standard deviation is calculated.

4) Similar distributions are made for $\dfrac{\overline{\lambda} - \lambda_i}{\Delta\lambda_i}$ and $\dfrac{\overline{\phi} - \phi_i}{\Delta\phi_i}$.

The distribution of $\left\{\overline{(\frac{1}{\rho})} - \frac{1}{\rho_i}\right\} \Big/ \Delta(\frac{1}{\rho_i})$ for both the IEP and the HPD events is plotted in histogram form in Fig. 3. In Table 4, the standard deviations of all the distributions for the HPD and the IEP are given in columns 1 and 2 respectively. Since the errors have been normalised with respect to the GRIND error, one would expect the standard deviation for the IEP events to be about 1. In fact it has been known for some time that the GRIND errors for $\frac{1}{\rho}$ and ϕ are slightly overestimated and the error for λ is underestimated, and this probably accounts for the deviations from unity in column 2. The measurement errors for the HPD events are seen to be clearly smaller than those for IEP. In column 3 the ratio of the standard deviations $\sigma_{HPD}/\sigma_{IEP}$ is given.

Comparison of external errors

	HPD	IEP	$\frac{\sigma_{HPD}}{\sigma_{IEP}}$
Standard deviation of $\frac{1}{\rho}$	0.68	0.99	0.69
Standard deviation of λ	0.92	1.15	0.80
Standard deviation of ϕ	0.64	0.87	0.74

Table 4

b) Comparison of χ^2 for four-constraint fits

Of the five events we used for the repeated measurements, three of them were four-constraint fit events. For each of these events, the histogram of the values of χ^2 found with each of the measurements is plotted in Fig. 4. These histograms show that the HPD results are extremely consistent.

Measurement speeds

Finally I will give some brief details on the measurement times.

a) Scan table

The average rate of measuring is 6 events/hour (i.e. 10 minutes per event). This time includes:

1) the scanning of the pictures for suitable events;
2) skipping over frames without events;
3) the measuring of the events.

The time actually spent measuring an event is about 5 minutes.

b) HPD

During an actual hour's production run, a rate of 54 events/hour was achieved. The average time for completely measuring an event is about 22 seconds. For the events we are measuring, an abnormal scan is needed in about 40% of the cases. One reason for this rather slow measurement rate is that the HPD Mark I, which we have at CERN, was designed to work with the IBM 709 computer, and we are not able to take advantage of the increased computing speed, which the 7090 now gives us.

Reference

1. GRIND MANUAL, Section C, EXTER, CERN 1962.

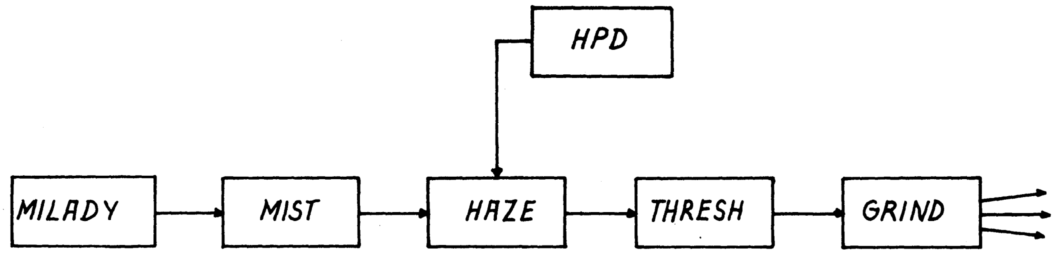
Figure captions

Fig. 1 Analysis sequence of HPD events.

Fig. 2 Comparison of χ^2.

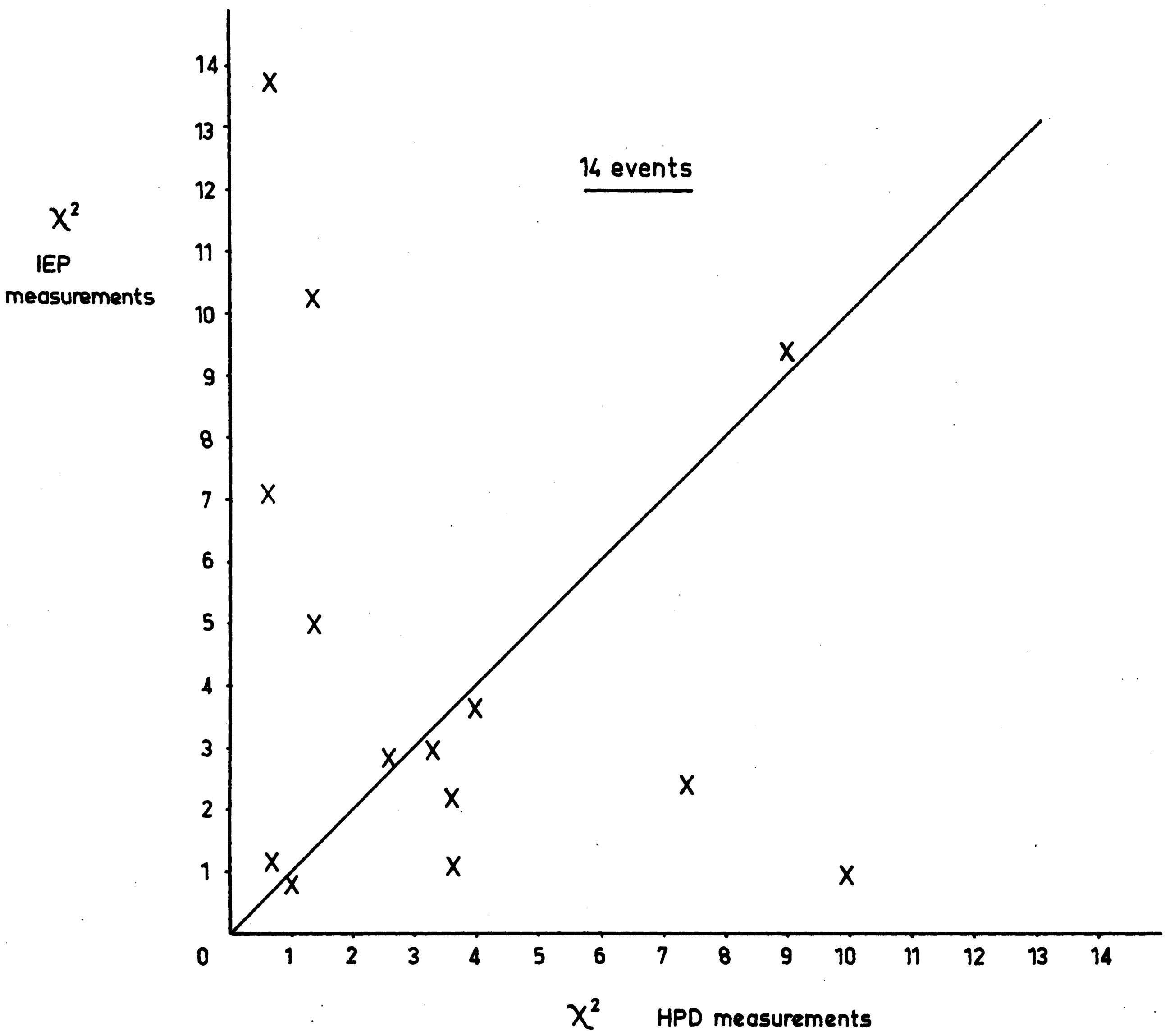
Fig. 3 Distribution of $\left\{ (\frac{\overline{1}}{\rho}) - \frac{1}{\rho_i} \right\} / \Delta(\frac{1}{\rho_i})$.

Fig. 4 χ^2 distributions for repeated measurements.



HPD
MILADY
MIST
HAZE
THRESH
GRIND

FIG. 1



14 events
χ^2
IEP measurements
χ^2
HPD measurements
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Fig. 2

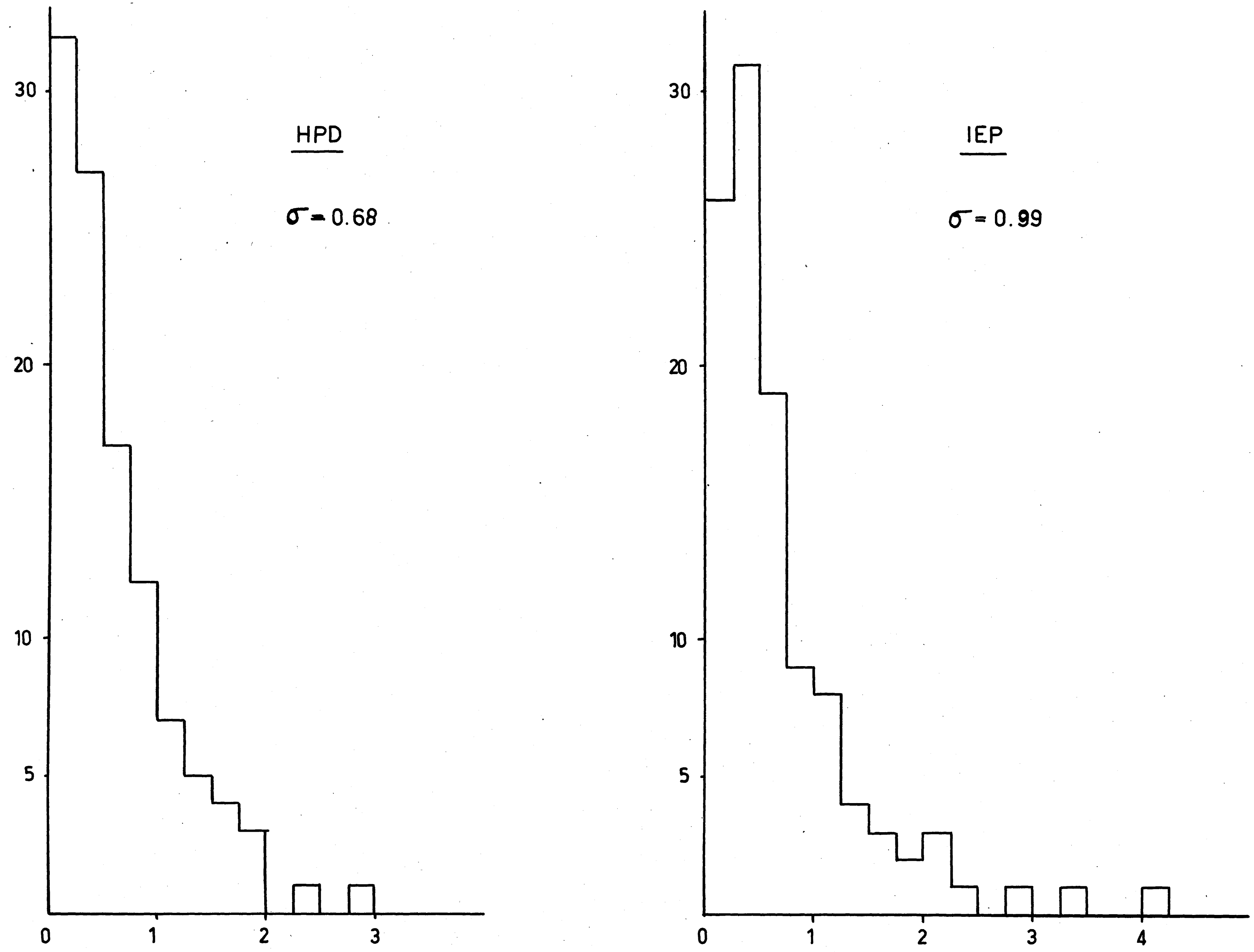
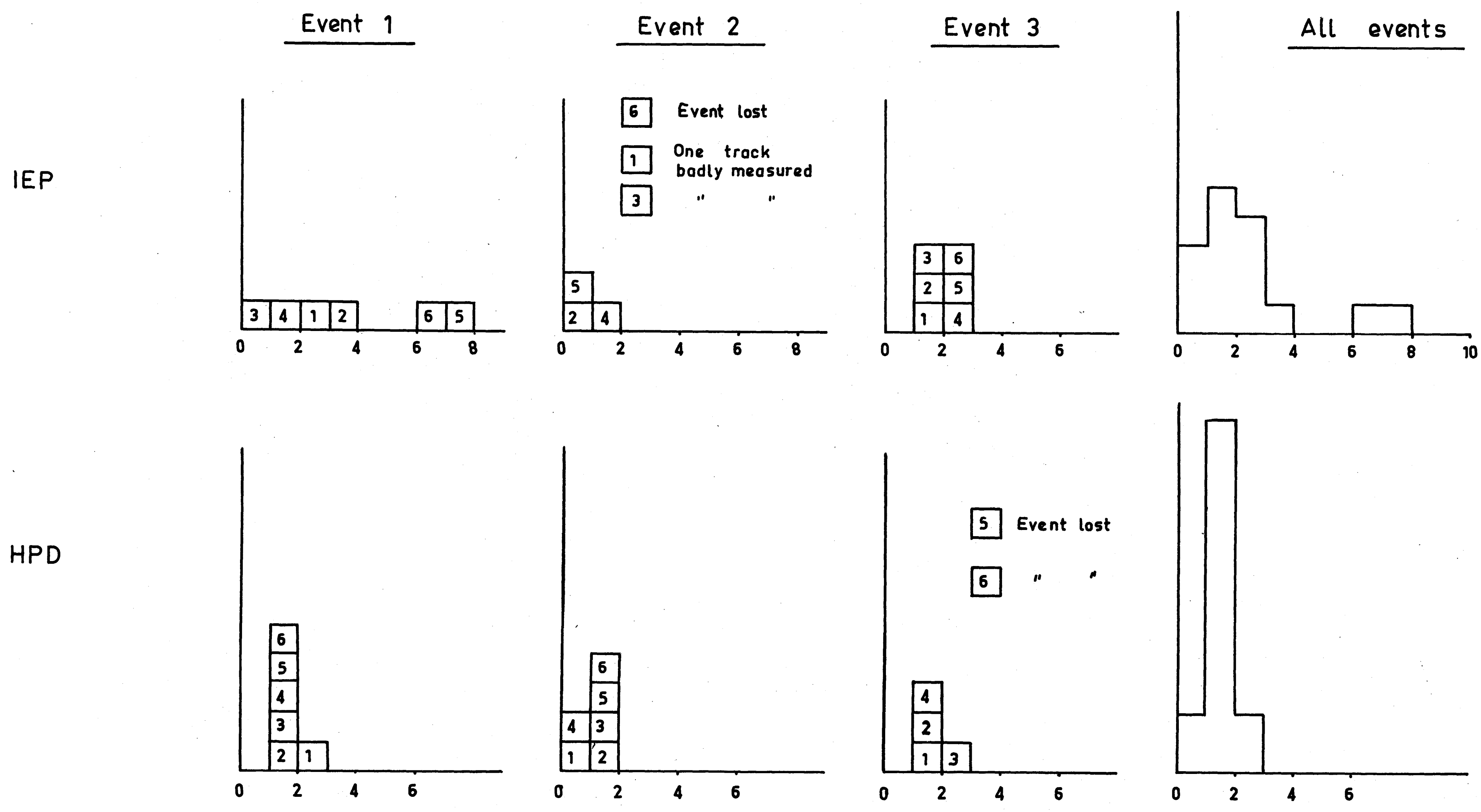


Fig. 3



Event 1
Event 2
Event 3
All events
IEP
HPD
6 Event lost
1 One track badly measured
3 " "
5 Event lost
6 " "

Fig. 4

DISCUSSION

SOOP: Comparing the values of $\Delta\frac{1}{\rho}$ for HPD and IEP results is not very conclusive if multiple scattering is not taken into account particularly for low energy tracks. You should compare the same points measured repeatedly on HPD and IEP.

HOWIE: Multiple scattering is not taken into account but the tracks are mostly of high energy.

STRAND: Do you have a check on fiducial separation in MIST?

POWELL: Not at present. The program is being rewritten to include additional checks.

BURREN: When were tracks counted as successful?

HOWIE: They had to be measured correctly in all 3 views to be considered successful.

STRAND: At Brookhaven we compare HPD and IEP measurements by suppressing one track in the fit and looking at the missing mass. Longitudinal and transverse momentum balances are also compared.