PRESENT PERFORMANCE OF THE WEIZMANN INSTITUTE-TECHNION SPIRAL READER SYSTEM

Weizmann Institute-Technion SR Collaboration(*)

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1. General Description

We describe in this paper the present performance of the Spiral Reader, which is a collaboration project between the Weizmann Institute and the Technion. Our Spiral Reader (SR) is based on the mechanical-optical hardware identical to the Berkeley SR II. The control electronics, interface to the PDP-9 computer, and on-line software were completely designed and implemented by our group. The whole system was briefly described previously[1-2]. Figure 1 shows an overall view of our SR.

In very broad terms the timetable of the SR project was as follows:

Mid 1968 - General planning and placement of order for the mechanical-optical hardware
1969 - Design and construction of electronics; design and writing of on-line and off-line software
1970 - Testing and running-in of whole system
1971 - Beginning of production measurement

The Spiral Reader was built by a quite small subgroup of the experimental high energy group - and there was at no time a special group involved exclusively with the SR problems. During the construction and testing phase the whole manpower involved was approximately the following: 1.5 physicists, 1.5 senior programmers, 1 engineer, 2 technicians. Only during later running-in period and during production did a larger number of physicists and programmers get partly involved in the different aspects of the analysis system. Thus the relatively small number of people involved in the project required a careful assignment of priorities, and a number of important improvements and developments had to be postponed until proper manpower was available.

One has to mention that a special problem, was incurred by the off-line computer. All off-line programs were originally run on a home built GOLEM A computer (roughly IBM 7094 equivalent) and the proper conversion of the programs had to be made. Very early though, the GOLEM became overloaded and an IBM 370/165 was obtained. Thus another major reconversion of programs had to be achieved (during 1971) and this severely taxed our limited manpower and caused delays to several projected developments.

2. Performance

The first experiment which is being performed by our Spiral Reader is π^+p interactions at 5 GeV/c, taken with the SLAC 82" Bubble Chamber on 46 mm single-strip film.

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We measure all nuclear interactions except 2-prongs (of which a sample was measured).

Until how we measured approximately 140,000 events. Of these we consider about 100,000 measurements completely good. The unacceptable measurements were performed during the running-in and early production phase when improvements were still being continuously performed. Also during this early phase - the off-line computer was completely over-loaded and only a very small fraction of the measurements could be run. Thus as we had no good check on the quality of measurements, a sizeable number was lost due to hardware malfunctioning before it was detected.

Of the acceptable measurements we have a DST of 41,000 events, and some preliminary results will be discussed in Section 3. The rest of the measured events are in the stage of being processed, through the analysis programs.

The present measuring rate on our Spiral Reader is 40-50 events/hour. The total average weekly rate for a 16 shift week is about 3,000 events/week.

The measuring process at the moment includes manual measurements of 4 fiducials and full crutch pointing. This means that one crutch point is placed on every track. This procedure, while quite time consuming during measurement was considered helpful for the success of events through POOH.

A significant increase in the rate of measurement is expected in the coming months due to 3 main causes:

(a) Introduction of minimum crutch points instead of full crutch pointing. With proper training of our measurers, no significant increase of loss in POOH should occur while increasing the speed of measuring by 30-40%.

(b) Introduction of the software for semi-automatic fiducial measuring (see Section 7), by performing a small spiral around each fiducial. This may again increase the rate by 20-30%.

(c) Further training of our measurers, and reducing down time of the SR.

The success rate of the SR measurements through the various off-line programs POOH, TP and SQUAW is summarized in Table 1 for a sample of 5239 events. The overall success rate of 73% is very comparable to that of manual machines (even though they have no POOH failures). This figure for the overall success rate holds also for a much larger sample of 59,077 events, as is shown in Table 2 (Item IV).

It should be noted that the 27% which fail, include 5% of operator rejects, which are classified in Table 1a. The operator rejects are events rejected by the SR operator before their measurement and are presumably unbiased rejects. As these events were not even measured, the 3rd column of Table 1 summarizes the success rates of measurement excluding the operator rejects.

The events that failed POOH-TP-SQUAW were sent to remeasurement on the SR. A sample of the results of SR remeasurements are summarized in Table 3. It is seen that POOH-TP-SQUAW failure went up from 27% to about 44%. It should be noted, though, that in this sample operator rejects were sent back to remeasurement too and these will usually be rejected again by the operator. Thus normally the POOH-TP-SQUAW rejects are expected to be considerably smaller than 44% and it is planned to do the 2nd measurements on the SR.

Table 1. Success of SR Measurements

Sample: 20 rolls, 5239 events; measured: Feb-March 1972

	No. Events	Fraction Total (%)	Fraction of Non-Operator Reject (%)
Successful SQUAW	3820	73.0	76.9
SQUAW Failure	405	7.7	8.2
TP Failure	218	4.1	4.3
POOH Failure	533	10.2	10.6
Operator Rejects	265	5.0	-
Total	5239	100%	100%

Table 1a. Operator Rejects

	No. Events	% Total
Wrong Event Type	81	1.5
Vertex Obscured	53	1.0
Out of Fiducial Volume	26	0.5
Fiducial Not Measurable	20	0.4
No Event on Frame	14	0.3
Others	71	1.3
	265	5.0%

Table 2. Ionization and Auto-Decision Results

59,077 Events; 1st measurement

Status		No. Events	%	
I.	Automatic Decision			
33033		32639	55.2	
II.	Physicist Decision			
32022	Ionization Convergence Failure	221	0.4	13.7%
32025	"Bad" Hypothesis has better χ^2_{bub} by 2	403	0.7	
32033	No acceptable ionization χ^2	2272	3.8	
32044	Too many ambiguities ($\geq$ 3)	1371	2.3	
32055	Resolvable ambiguities	3506	5.9	
32066	Too many 4C ($\geq$ 2)	323	0.5	
32077	Reduced ND	69	0.1	
III.	Physicist Reject			
31022	Ionization Convergence failure	106	0.2	3.9%
31025	"Bad" Hypothesis has better χ^2_{bub}	769	1.3	
31033	No acceptable ionization χ^2	229	0.4	
31044	Too many ambiguities (> 4)	2	-	
31055	Resolvable ambiguities	157	0.3	
31066	Too many 4C	15	-	
31077	Reduced ND	182	0.3	
31088	Kinematic fails	773	1.3	
	Unmeasureable and Wrong Event Type	33	0.1	
IV.	POOH, TP, SQUAW Fail + Operator Rejects	16007	27.0	
		59077		

Table 3. Remeasurements Results

10 Rolls; 2nd Measurement

Status		No. Events	%	
I.	Auto Decision			
33033		606	39.0	
II.	Send to Physicist			
30022	Ionization Convergence fail	4	0.3	17.5%
30025	"Bad" Hypothesis has better χ^2_{bub} by 2	33	2.1	
30033	No acceptable ionization χ^2	40	2.6	
30044	Too many ambiguities ($\geqslant$ 3)	49	3.2	
30055	Resolvable ambiguities	75	4.8	
30066	Too many 4C	4	0.3	
30077	Reduced ND	13	0.8	
30088	Kinematic Fails	53	3.4	
	POOH, TP, SQ-Fail + Operator Reject	677[a]	43.5[a]	
		1554		

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[a] These numbers include all the operator rejects of measurement 1. In normal operation, operator rejects will not be sent to remeasurement, thus significantly decreasing these failures.

Malfunction of the hardware can occur, such that it does not put the SR out of operation but still produces poor measurements. In order to avoid loss of measurements from this cause, a sample of each day's measurement is examined within 24 hours. The following criteria are applied:

(a) The POOH success rate is required to be above 85% and overall success above 65%.

(b) The beam FRMS is required to peak below ∿3.5 least counts.

(c) The beam pulse height is required to be concentrated between 19-23.

In case of failure of any of these criteria, the measurement is stopped and the SR is turned over to the maintenance crew.

A reasonable amount of our effort went into program development and logistic setup for a system that could handle the 200,000-400,000 measurements per year. For this purpose bookkeeping program JUNGLE was developed which keeps the status of all the events and controls the events sent to measurement; it also receives feedback from the program SELECT as to which measurements were put on DST and which failed inside the system and for what reason.

Rather careful procedures had to be setup for the daily debug checking of a sample of measurements (described above), as well as for the complete production running and proper tape storage.

3. Results

The first measurements of our Spiral Reader were performed on an experiment of π^+p interactions at 5 GeV/c.

We shall show some results of 4-prong interactions from this experiment, based on a preliminary DST of about 40,000 events (after physicist checking, but no remeasurement).

A. Reaction $\pi^+p \to p\pi^+\pi^+\pi^-$ (4C, 9620 events).

Figure 2 shows the invariant mass of $p\pi^+$. Figure 3 shows the invariant mass of $\pi^+\pi^-$ when the other $p\pi^+$ combination is the Δ^{++} region. There are seen clear signals for the $\Delta^{++}(1236)$, ρ^0 and f^0, and both location of these resonances and their widths corresponds to presently acceptable values.

B. Reaction $\pi^+p \to p\pi^+\pi^+\pi^-\pi^0$ (1C1, 12,300 Events).

The distribution of $M(\pi^+\pi^-\pi^0)$ is shown in Figure 4. The $(\pi^+\pi^-\pi^0)$ invariant mass, when produced with a Δ^{++} is shown in Fig. 5, in 10 MeV intervals. The narrow η and ω mesons appear as very prominent features, and are at their correct central values, with widths which are somewhat better than for hand measurements.

4. Quality of Measurements.

The invariant mass distributions of the π^+p 5 GeV/c experiment (Figures 2-5) provide some evidence that the SR measurements are "reasonable". The distribution of the FRMS (= deviations from fitted tracks projected onto the film) of a sample of measurements is shown in Fig. 6. They peak between 2-3 least counts (4-6 microns) and are somewhat better than FRMS deviations obtained on a manual measuring machine for the same film.

In order to investigate in detail the quality of measurements of the SR a sample of the film was measured by a Vanguard manual measuring machine. The hand measurements were passed through the identical TP geometry program as the SR measurements. We compared in detail the geometry results of all tracks of 1450 events.

For all events we looked at a quantity (q_{SR} - $q_{Van}/\Delta q$) where q was the momentum, phi and dip of each track as measured by the SR and the Vanguard. For all outgoing tracks these distributions were reasonably centered on 0 with widths of about 1. On the other hand the beam distribution showed small shifts corresponding to about 30 MeV on the momentum and about 0.1° on the dip. We also examined the pulls of about 9600 4C events and they show qualitatively similar effects.

While we do not yet understand the exact source of this beam shift, we are now conducting an investigation in order to understand it and eliminate it. In order to correct the measurements already made we use the following procedures in SQUAW: (a) the values of the beam momentum and dip are modified by a small correction factor (this was not yet done on the events on our present DST), (b) a beam averaging calculation is done (following a LRL procedure[3]) where the measured beam values are averaged with a beam mapping based on 4C fits where the beam was unconstrained.

Possible sources for the observed beam shift and ways of improvement that are being looked into are the following:

(a) Film tension. LRL found out that the tension under which the film is kept during measurement could cause such distortions and suggested methods to eliminate it.

(b) Improved calibration. The calibration could be improved by (i) better parametrization of the fit, and by (ii) investigating the effect of the differences in the tension under which calibration plate and usual film are measured. (iii) Furthermore, we are now doing a separate calibration in each of the 3 views - while previously calibration was performed in view 3 only.

(c) Investigation of the vacuum of the three film gates, and its improvement.

We also compared the overall results of passage through off-line programs of hand-measurements (Vanguard) and SR measurements on a sample of events. The TP+SQUAW failure was 13% on the hand measurement 10% on SR measurements. Of the 586 events which passed successfully the whole analysis system, in 88% there was agreement between the Vanguard and SR measurements. Of the remaining 12%, further reexamination showed that in about 8.5% the SR assignment was considered correct, in 1.5% the Vanguard was correct and in 2% it was undecided (hardship cases).

5. Calibration

For calibration we use the LRL "Chicken-walk" film-strip of a pattern of 7 x 15 crosses at 15° to the radial direction. The calibration film is just placed in the film gate and is not attached to the film transport system and therefore not subject to the same tensions as the real film during measurements.

The calibration program CALB originates from the CERN program SCALP with considerable modifications[4]. The input is completely rewritten to conform to our SR output. The fit itself is performed to a 17 parameter function which is similar to the LRL formulation. It was found that some of these parameters have only a minor effect in the fit in most cases. A study is presently being done on improvements on the parametrization of the fit.

For each calibration measurement we take 7 spiral runs. Originally we calculated 7 complete fits (and sets of parameters) corresponding to these separate spiral-runs. We subsequently found out that the fit was very considerably improved when all the fits of the 7 spirals are being used together. Thus we are now performing a grand fit to all hits for all 7 spirals for each cross. In this way there are typically about 130-140 hits on each cross. We pick up on calibration about 90 crosses. (The others are beyond the range of the spiral or not enough hits are obtained on it). We pay especial attention to there not being any "fractional" crosses being picked up as these can distort the fit considerably. In making the grand fit to all hits, we obtain χ^2 of typically 500-600 for about 90 points and 17 parameters. For this purpose our χ^2 is defined as the sum of differences between the fit and the expected position of the cross (i.e. the error is set arbitrarily to $\Delta=1$ ℓ.c. = 2μicrons). This means that typical residuals on the coordinates of each cross are about 1.5-2.0 least counts on x and y.

We have not made as yet a comprehensive study of systematics of the residuals from the fit to the calibration pattern, but this problem is under study.

An interesting point was found in relation to the x-y measurement of the crosses. A feature of the calibration programs allows several measurements of the x-y coordinates of the calibration plate crosses to be made by the SR stage just prior to making the spiral run - then calculating the average position. Alternately the cross positions were measured on a Vanguard measuring machine and introduced as data into the CALB program. It turned out that the χ^2 of a fit based on the Vanguard measurement of the crosses is significantly better than when using the SR measured x-y coordinates of the crosses.

6. Ionization Measurement and Auto Decisions

In our Spiral Reader the pulse height of each hit is digitized into 32 levels, and output in 5 bits (i.e. PH $\leq$ 31). The discriminator level commonly used is 7. In the program POOH the PH data for all points of each track with radius $\leq$ 3500 R-counts (i.e. about 5000 microns on film), are used to calculate an average PH for the track. Typically one gets $\overline{\text{PH}} \simeq 30$ for stopping tracks and 20-22 for beam tracks.

In SQUAW, for each hypothesis a fit is made to the pulse height data and an ionization χ^2 is obtained. Our treatment follows generally the LRL procedure. All 3 views are used as independent data. Before making the fit a check is made of the consistency of the 3 views, and views that are very inconsistent are not used. The fit is made by first obtaining the projected bubble density α for each track in each view (taking into account different aspect angles for the 3 views). Then all tracks are fit simultaneously for each kinematic hypothesis where the functional form of the "predicted" PH (PHP) is:

$$\text{PHP} = \text{PHMAX}\left[1 - \left(1 - \frac{\text{PMIN}}{\text{PHMAX}}\right)^{\alpha}\right] \qquad (1)$$

and the quantity fitted is PMIN. PHMAX is the average PH of stopping protons (29.5 is used in our experiment). The χ^2-ionization (= χ^2_{bub}) is obtained from minimization of difference of measured and predicted heights.

The distribution of χ^2-ionization for a typical sample of 4-prong events is shown in Fig. 7.

It was found that the Spiral Reader pulse height measurement consistently underestimated the ionization of low momentum tracks ($p \lesssim 150$ MeV) and consequently gave very poor χ^2_{bub} for these events. As such tracks are distinguishable kinematically (by range), we introduced a recent modification which excludes such tracks from the χ^2_{bub} calculation.

Our SELECT program, which follows SQUAW, subsequently uses the χ^2-ionization value for deciding on the automatic selection of the SQUAW hypothesis. The SELECT program makes one of the following decisions:

a. Event is unique (1 hypothesis put on DST).

b. Event is intrinsically ambiguous (several hypotheses sent onto DST).

c. Event is doubtful (referred to physicist for final decision).

The criteria developed for the program SELECT are hopefully general, but the specific values of the quantities mentioned below refer to our π^+p experiment at 5 GeV/c.

The main procedure of the program SELECT in making decisions is as follows:

1. The kinematic results of SQUAW are examined. Here a P_{χ^2} cutoff is applied, missing mass hypotheses are rejected if a higher constrain corresponding fit exists, and a minimum value of missing mass is required for genuine missing mass hypotheses.

2. The hypothesis with the minimum χ^2-ionization is required to be below a specified value (we require $\chi^2_{bub} \leq 1.5\ (3 \cdot \mathrm{NTK} - 1)$, where NTK is the number of tracks in the fit). If not the whole event is put in category (c) and sent to the physicist.

3. Assuming that condition 2 holds, the other hypotheses are classified as to whether they fallwithin KQ units of χ^2-ionization (KQ = 4 in our experiment) of the hypothesis with minimum χ^2-ionization. Those that differ from the minimum χ^2-ionization by more than KQ are rejected. Those that fall within the range KQ are classified "potentially ambiguous".

4. The event is examined whether at this stage it falls into one of a number of potentially troublesome categories. These include: more than 2-fold ambiguous, more than one 4C hypothesis, reduced number of kinematic degrees of freedom, or a better χ^2_{bub} (by 2 units) of one of the kinematically rejected hypotheses (this indicates possibility of a higher constrained fit not having succeeded for various reasons). These cases are sent to the physicist for examination.

5. Finally those events in the "potentially ambiguous" class are now further analyzed by the program to determine whether they are "intrinsically" ambiguous, or whether a physicist could resolve them on the scanning table. Events where a physicist could make a decision include those cases in which the SR did not measure ionization on one or more tracks (short tracks, flares, discrepancies between PH on different views causing rejection, etc.). These tracks could be crucial for the decision. Therefore, the program looks at the separate hypotheses of the "potentially ambiguous" events track by track; if different mass assignments on any track causes its predicted ionization to be different by more than a factor FI (in our experiment FI = 1.3) that event is sent to the physicist as a resolvable ambiguity. If on the other hand in no case do different mass assignments cause a different predicted ionization by more than factor FI, the event is classified as "intrinsically ambiguous" and put in category (b) above.

The events sent to the physicist, or any other event can be forced into any kinematically accepted decision by an overriding decision card which SELECT recognizes.

We tested this system on a sample of 1106 events. These events were fully physicist checked, and then the physicist decisions were compared against the automatic decisions of SELECT. Those cases of disagreement were again examined very carefully to determine whether the automatic decision or the physicist were right. The results were as follows:

89 events (8%) - had disagreements. Of these
23 events (2.1%) - SR was considered mistaken; of these again only
9 events (0.9%) involved wrong unique hypotheses.
66 events (6%) - the physicist was considered mistaken; of these
26 events (2.4%) involved wrong unique hypothesis.

After the comparison was made, several criteria of SELECT were improved, which should result in even considerably smaller SR errors. On the other hand while some of the physicist errors could be attributed to inexperience or carelessness, we believe that the study shows conclusively that basically the number of SR auto-decision errors are smaller than if checking were fully done by physicists.

The distribution of the hypothesis with the best χ^2_{bub} versus the next best χ^2_{bub} on a sample of events is shown in Fig. 8. The comparison of the predicted versus measured pulse height is shown in Fig. 9.

The results of the Auto-decision systems for the approximately 40,000 events on the DST are shown in Table 2 (for first measurement). We note that about 18% of all events were sent to the physicist. About 4% of these events were rejected by the physicist. They include possible strange events (not all strange hypotheses were included in SQUAW), possible Dalitz pairs which were not yet treated properly in SQUAW, as well as candidates for remeasurement. Of those 13.7% of the events resolved by the physicist, the biggest category are status 32055 (resolvable ambiguity), 32033 (no acceptable ionization χ^2) and 32044 (too many ambiguities). The improved treatment of curvy tracks, described above would considerably lower the number of events of status 32033 and allow them to go into the automatic decision category.

In Table 3 are shown the results of a sample of SR remeasurements; for this sample all events that did not get on the DST were sent for remeasurement (including operator rejects). About 55% of events successfully passed POOH, TP, SQUAW (and were not rejected by operator), compared to 73% for the 1st measurement. The fraction sent to the physicists for final decision is roughly the same (these have status words of "30,000" because they were not yet looked at by the physicist). Consequently we are now doing all 2nd measurements on the Spiral Reader.

Further improvements of ionization measurements being planned are as follows. Each hit on our Spiral Reader is composed of 4 PDP-9 words. Of these one word is reserved to get the pulse width at half-height. When this feature will be fully implemented we could calculate a quantity proportional to the pulse area. This will then permit us to use the pulse heights from a much longer section of track and thus improve considerably the evaluation of the ionization. That is expected to decrease considerably the number of events sent to the physicist as resolvable ambiguities and as too many ambiguities (status 32044, 32055).

7. Further Developments.

Plans for future development of our Spiral Reader System include the following items:

A. Hardware

1. Electronics for measurement of the pulse width of half height. This is expected to improve considerably the ionization measurement.
2. A new cage of handling 35 mm single-strip film.
3. A new cage and film transport for handling 35 and 50 mm 3-strip film.
4. Additional buttons and control for handling chopping and negative crutch points.
5. Electronics for pulse treatment of bright-field film.

B. Software

1. Software to support new hardware features above (specifically items A1, A3).
2. Semi-automatic fiducial measurement. We plan to perform a spiral scan of each fiducial of approximately 5 pitches (∿ 300 msec) - thus yielding about 10 points on each leg of the fiducial. A best fit to their intersection (similar to fit of crosses in the calibration program) will yield the best position of the fiducial. This scheme is intended to substantially increase the speed of measurement of fiducials, increase the accuracy of the measurement and reduce fatigue of the measurer. In this scheme the stage will be driven to the prestored approximate location of the fiducials by the computer, where the spiral will be performed (also by computer) without the necessity of operator interference. Preliminary results of calculated positions of the fiducials yield generally better reproducibility than hand-measurement of the fiducial location.
3. Improved treatment of filter and match - in particular handling of crutch points, overlapping tracks and matching procedures.

References

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3. S. Flatte, Lawrence Radiation Laboratory. Berkeley Group A Physics Note No. 664, 1968.
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Figure Captions

Fig. 1. Overall view of the Weizmann Institute-Technion Spiral Reader.

Fig. 2. $M(p\pi^+)$ for reaction $\pi^+p \to p\pi^+\pi^+\pi^-$, 5 GeV/c.

Fig. 3. $M(\pi^+\pi^-)$ for reaction $\pi^+p \to p\pi^+\pi^+\pi^-$, 5 GeV/c, when $p\pi^+$ is in Δ^{++} resonance.

Fig. 4. $M(\pi^+\pi^-\pi^o)$ for reaction $\pi^+p \to p\pi^+\pi^+\pi^-\pi^o$, 5 GeV/c.

Fig. 5. $M(\pi^+\pi^-\pi^o)$ for reaction $\pi^+p \to p\pi^+\pi^+\pi^-\pi^o$, 5 GeV/c when $p\pi^+$ is in Δ^{++} resonance.

Fig. 6. FRMS (= film deviations from fitted tracks) distribution for $\pi^+p \to p\pi^+\pi^+\pi^-$ 5 GeV/c.

Fig. 7. Distribution of ionization χ^2, for 4 prong events.

Fig. 8. "Best" hypothesis is the physicist decision based on scanning table. The scatter plot shows the χ^2-ionization for "best" hypothesis versus the next best χ^2-ionization. Those events falling within the broken lines are sent to physicist for decision, unless the ionization ratios of all corresponding tracks is less than 1.3.

Fig. 9. Distribution of predicted pulse height versus measured pulse height on tracks of hypotheses chosen by physicist. Broken lines represent typical errors.

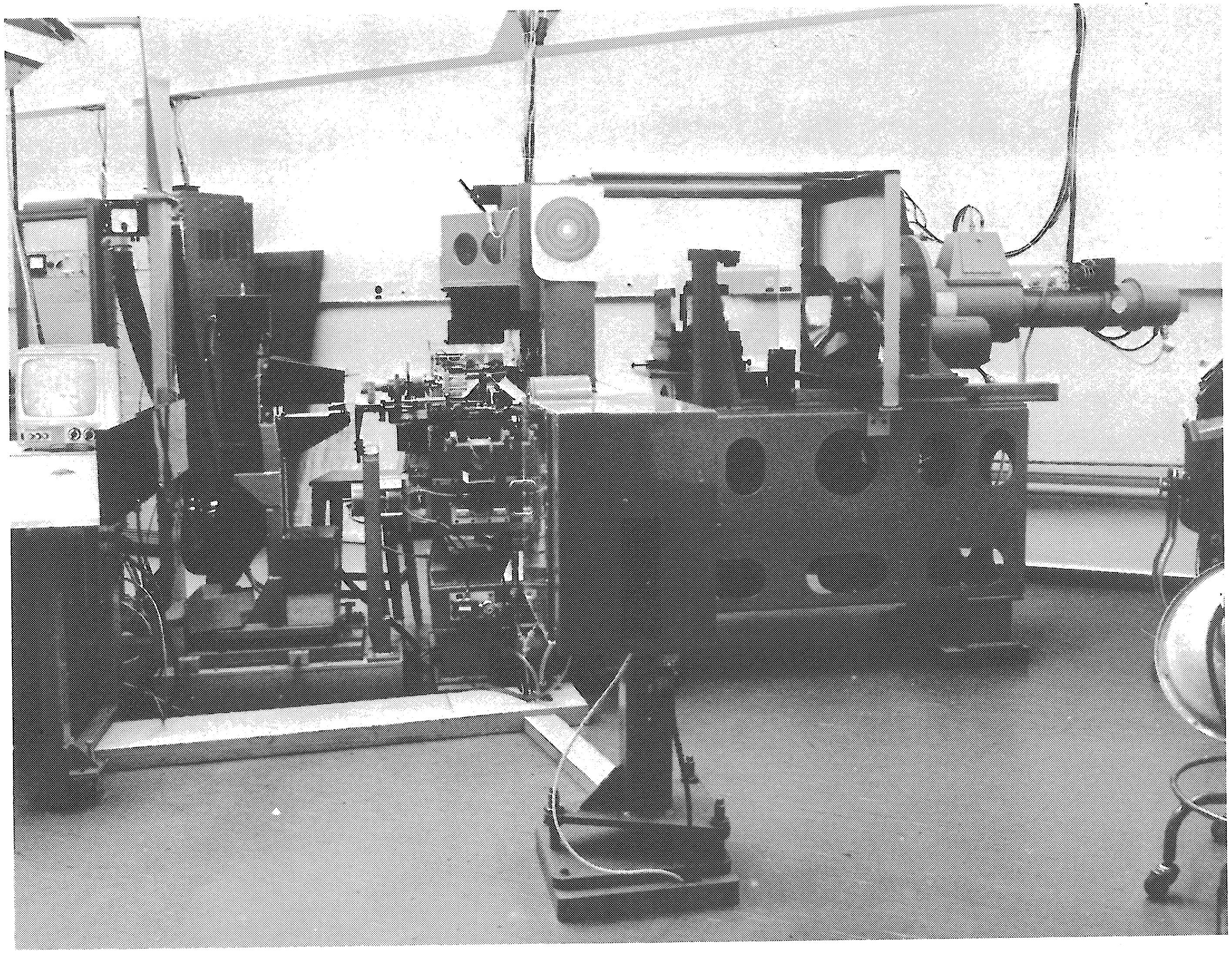

Fig. 1

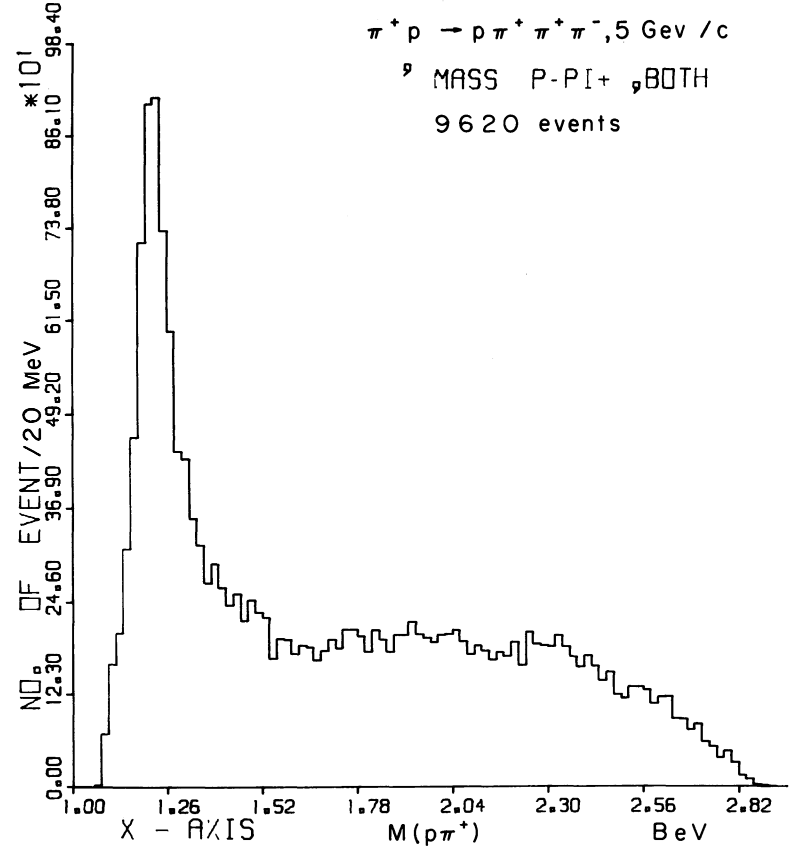
π⁺p → pπ⁺π⁺π⁻,5 Gev /c
, MASS P-PI+ ,BOTH
9620 events
NO. OF EVENT/20 MeV
*10¹
0.00
12.30
24.60
36.90
49.20
61.50
73.80
86.10
98.40
1.00
1.26
1.52
1.78
2.04
2.30
2.56
2.82
X - AXIS
M(pπ⁺)
BeV

Fig. 2

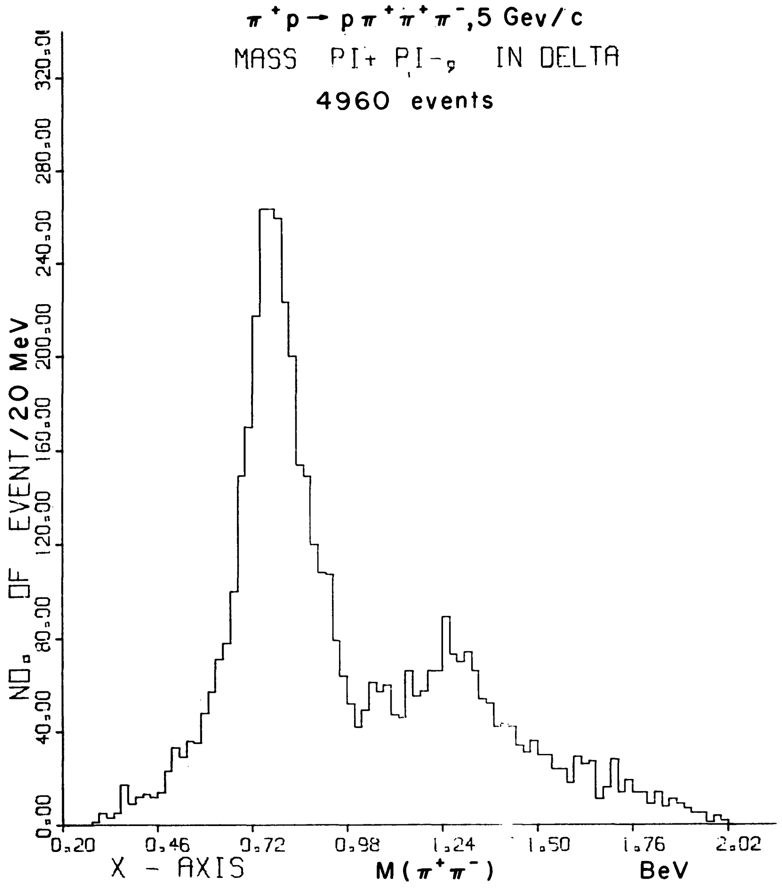
π⁺p → pπ⁺π⁺π⁻,5 Gev/c
MASS PI+ PI-, IN DELTA
4960 events
NO. OF EVENT/20 MeV
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
320.0
0.20
0.46
0.72
0.98
1.24
1.50
1.76
2.02
X - AXIS
M(π⁺π⁻)
BeV

Fig. 3

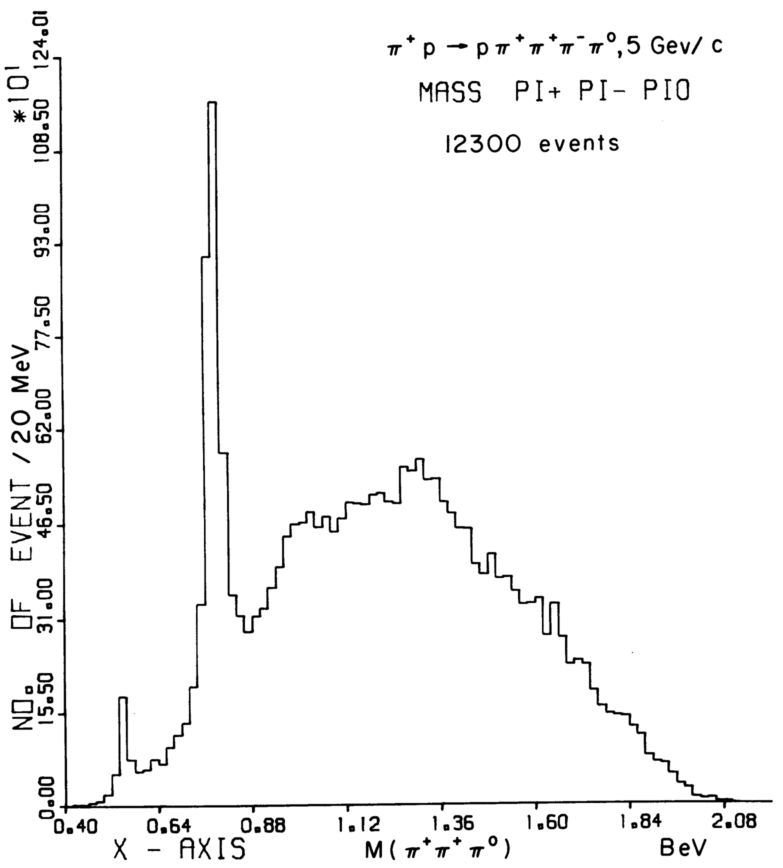
$\pi^+ p \rightarrow p\pi^+\pi^+\pi^-\pi^0$,5 Gev/ c
MASS PI+ PI- PIO
12300 events
NO. OF EVENT / 20 MeV
*10¹
0.00
15.50
31.00
46.50
62.00
77.50
93.00
108.50
124.01
0.40
0.64
0.88
1.12
1.36
1.60
1.84
2.08
X - AXIS
$M(\pi^+\pi^+\pi^0)$
BeV

Fig. 4

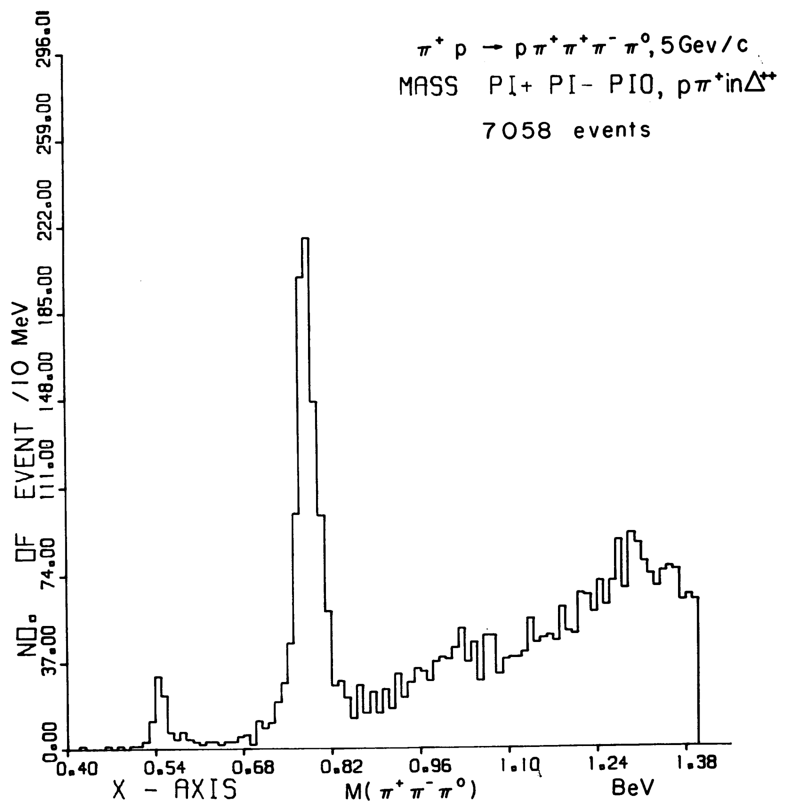
$\pi^+ p \rightarrow p\pi^+\pi^+\pi^-\pi^0$,5Gev/c
MASS PI+ PI- PIO, $p\pi^+$inΔ^{++}
7058 events
NO. OF EVENT /10 MeV
0.00
37.00
74.00
111.00
148.00
185.00
222.00
259.00
296.01
0.40
0.54
0.68
0.82
0.96
1.10
1.24
1.38
X - AXIS
$M(\pi^+\pi^-\pi^0)$
BeV

Fig. 5

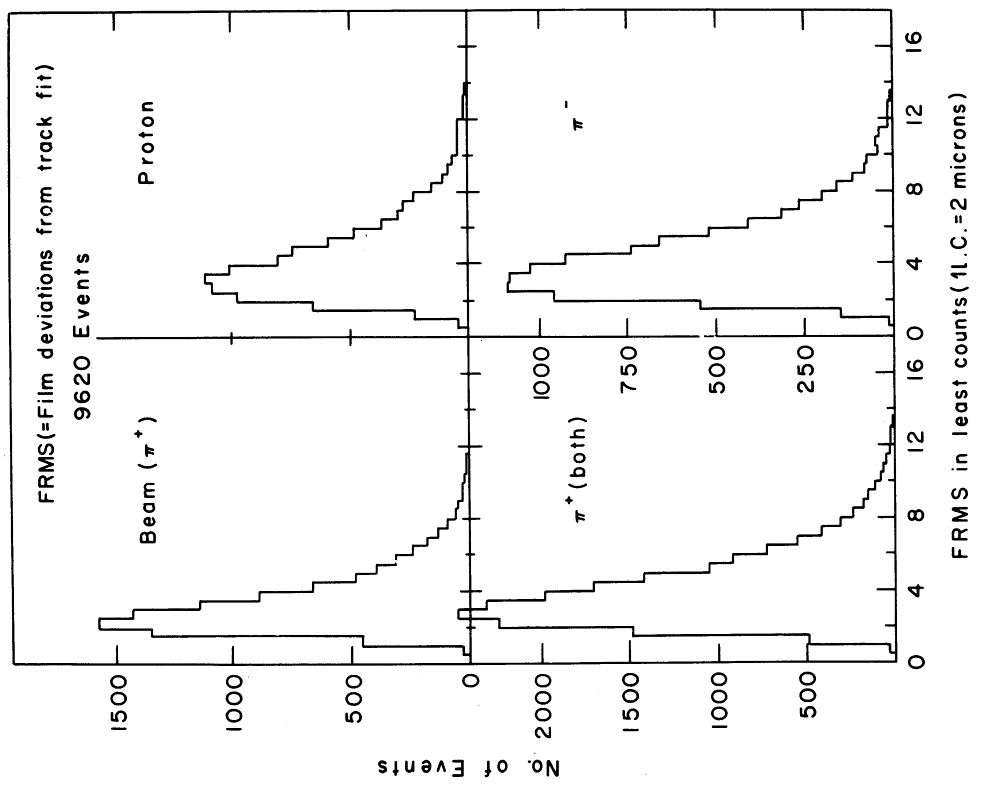
FRMS(=Film deviations from track fit)
9620 Events
Beam (π⁺)
Proton
π⁺(both)
π⁻
1500
1000
500
0
2000
1500
1000
500
1000
750
500
250
0
4
8
12
16
0
4
8
12
16
FRMS in least counts(1l.C.=2 microns)
No. of Events

Fig. 6

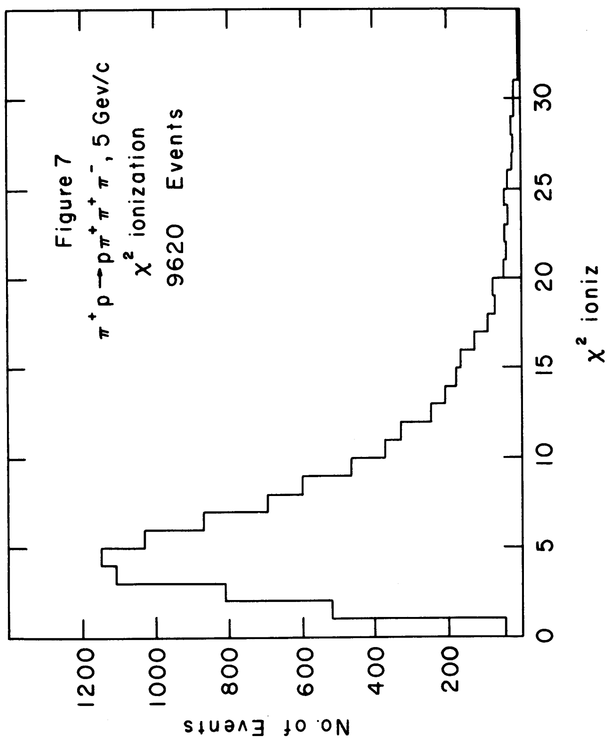
Figure 7
π⁺p→pπ⁺π⁺π⁻, 5 Gev/c
χ² ionization
9620 Events
1200
1000
800
600
400
200
0
5
10
15
20
25
30
χ² ioniz
No. of Events

Fig. 7

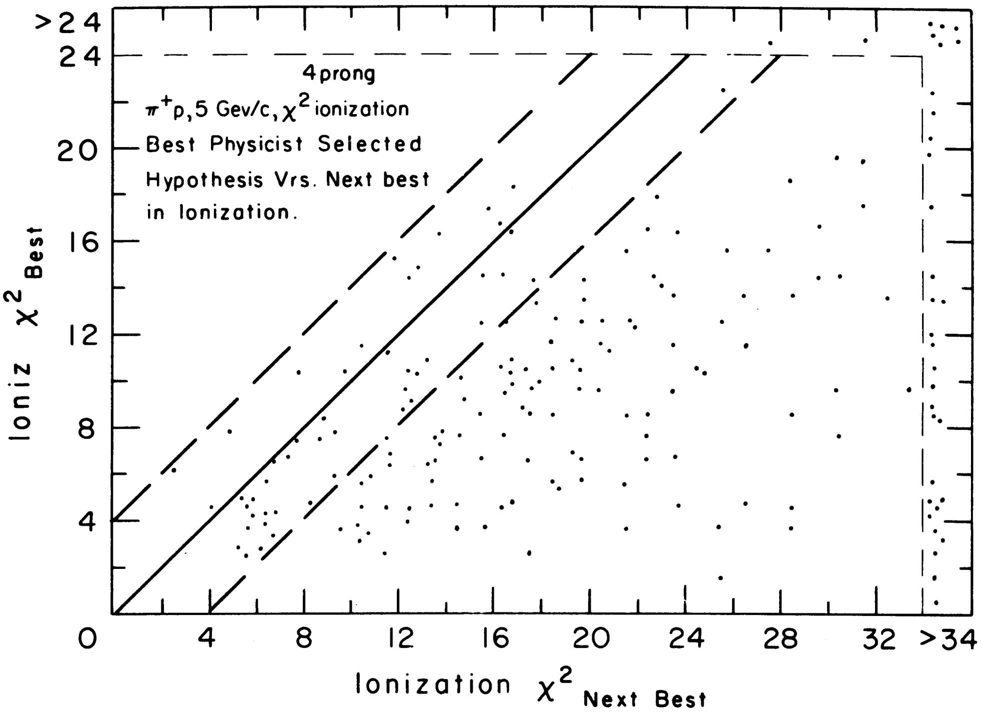
4 prong
π^+p, 5 Gev/c, χ^2 ionization
Best Physicist Selected
Hypothesis Vrs. Next best
in Ionization.
Ioniz χ^2_{Best}
Ionization $\chi^2_{\text{Next Best}}$
0
4
8
12
16
20
24
28
32
>34
>24

Fig. 8

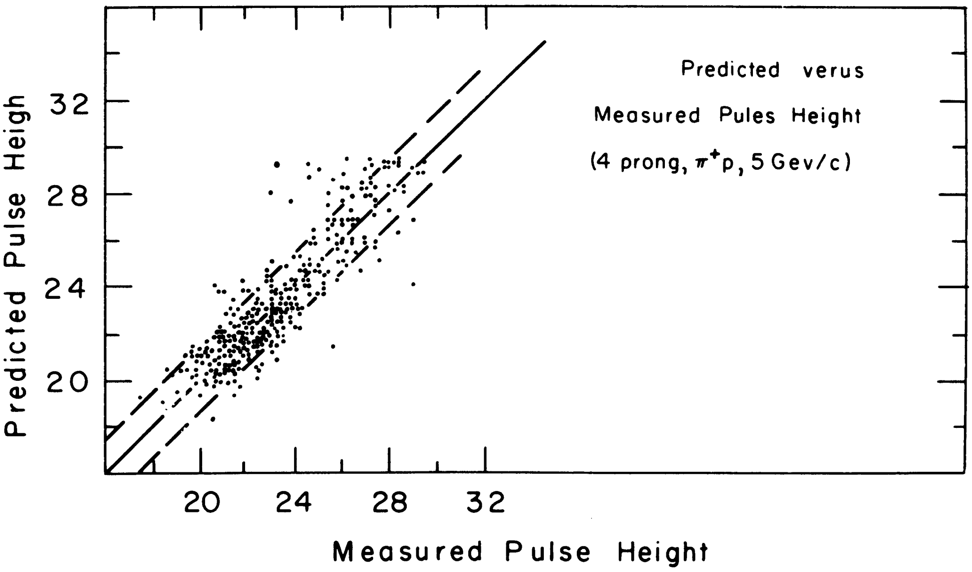
Predicted verus
Measured Pules Height
(4 prong, π^+p, 5 Gev/c)
Predicted Pulse Heigh
Measured Pulse Height
20
24
28
32

Fig. 9