CALIBRATION OF THE DANISH-SWEDISH SPIRAL READER (SAAB-TYPE)

S. Berglund, S-O. Holmgren and P. Lundborg,
Danish-Swedish Spiral Reader Project, Inst. of Physics, The University of Stockholm, Sweden.

Introduction

The Danish-Swedish Spiral Reader is no 1 of the four machines constructed and manufactured so far by SAAB-SCANIA in Jönköping. The principal design and performance is described in the status report(1). The purpose of this paper is to describe and discuss methods for the correction of geometrical distortions in this machine. Unlike in many other installations it was decided in an early stage to make the subtraction $\theta_{trailing} - \Delta\theta/2$ in the on-line computer. This subtraction did not work correctly for the last buffer in each spiral. This probleme obscured for some time the real distortion effects. The picture has now become more clear and we believe that we can separate systematic and random errors with sufficient confidence.

Chicken Walk Calibration

The calibration method using glass plate with a so called chicken walk pattern has been extensively used. Two types of patterns have been used both made by J. Heidenhain after drawings from CERN(2). The currently used one has 177 crosses the positions of which are known by microscope measurements.

The CERN program SCALP(3) has been used for the analysis of the measurements. Fig. 1 shows a typical result of the calculations for one spiral. In the use of this calibration method it was found essential that the slit is not too long and that it has an even sensitivity.

A simple method has been used to measure the sensitivity along the slit. A dark mask with a approx. 25 microns wide slit along the Y-axis has been placed in the optical path. The periscope is stopped and rotated so that the image of the light slit is perpendicular to the pick-up slit. The X-stage is then moved and the current from the PM-tube is plotted. Fig. 2a shows a typical plot from SRS-1. A mask is then placed over the slit to select a good part of the slit. If the sensitivity curve is not symmetric this can introduce a systematic difference between measuring on CW-crosses and straight lines or high energy track. The straight line will not be affected by an unsymmetric sensitivity-curve but Fig. 2b, 2c shows qualitatively the distortions on CW-crosses.

Beam track measurements at 19 GeV/c

The film currently measured on the Danish-Swedish Spiral Reader is from a 19 GeV/c pd experiment in CERN 2 m BC.

When measuring beam momentum in this experiment we locate a bubble in the middle of a noninteracting beam track and center the spiral on the same bubble in the three views. These measurements are then processed in the filter and geometry programmes POOH[4] and THRESH[5].

When comparing the distribution of $\frac{1}{\rho}$ (ρ= radius of curvature of helix fit in THRESH) for the backward and forward part of the track a highly significant shift in the mean values is found. The distributions are shown in Fig. 3 and in Fig. 4 results from the same film measured on a conventional ENETRA-machine is shown.

The widths of the distributions are almost the same, which indicates that the effect is due to some stable systematic error. The size of the effect could be estimated in the following way:

Nominal momentum 19.2 GeV gives $\frac{1}{\rho} = \frac{0.3\times17.34}{19.2\times10^3} = 27.094.10^{-5}$ cm $^{-1}$

Sagitta $S = \frac{L^2}{8R} = \frac{27.094\times10^{-5}}{8}\ 60^2 = 1210\ \mu$ in space $= \frac{1210}{14} = 86\ \mu$ on film

Magnification is ~14

The full effect is around 7% and if we assume the effect to be equally shared (in fact it is not) between incoming and outgoing track it implies an effect of 3 μm in sagitta over full radius (50 000 μ) that is 1.5 least count in xy.

When fitting the (r, θ τ x y)-transformation parameters (r_o, θ_o, r_{count}, x_o y_o) from chicken walk measurements one gets residuals in x and y for each cross fitted.

These residuals should in principle contain the systematic effects not taken into account by the transformation but of course also random fluctuations from measurements.

It is customary to make a table of these residuals and use it to correct the measurements in the xy-system before entering the geometry calculations in THRESH.

This has been tried on the beam track measurements but with no satisfactory effect on the curvature difference between the forward and backward parts of the track.

Measurements of artificial straight lines and comparisons with chicken walk measurements

We have to our disposal a glass-plate with ingraved straight lines in a square grid. These lines are measured in the same way as the CW-plate i.e. with constant low periscope speed (110 counts/rev).

The points on the lines in the SR x and y direction are filtered out and fitted to straight lines in a computer programme LINES[6].

Fig. 5 shows the residuals from such a fit along the x-axis (beam direction made on measurements taken at the time of the mentioned beam track measurements. Each point is the average residual over 500 r-count (~5 digitizings) and four spirals are superimposed.

The profile of the line shows a distortion which has a curvature of the right sign and size to account for the systematic effect on beam track measurements.

The figure also shows that the random spread of the measurement around the average profile is smaller than the systematic effect. This offers a possibility to separate the systematic effect from the random spread.

To purify the systematic effect a table of mean residuals from four spirals is determined. This table of residuals is then applied as a correction to 12 spirals including the four first ones. The measurements are spread over a period of one week. As can be seen from Fig. 6 there is no detectable systematic effect left after this correction and the random spread appears to be the same along the line. The projection of this plot is given in Fig. 7. The standard deviation in this distribution is 0.5. When single digitizings are used we find a standard deviation of ~0.9 counts. These measurements are made on an ideal straight and sharp line which is free from Coulomb error. We therefore claim that the setting error attributed to the machine itself on a single digitizing amounts to 1.8 μm.

To investigate how much of the systematic effect could be attributed to the measured line itself the line was turned 180^{o}. Fig. 8 and 9 shows results from normal and rotated line position and the differences are indeed small which justifies our assumption that the line itself is straight enough not to need any separate correction. This is also supported by measurements in the SR xy system.

An interesting question is now "how does these result compare with the result from CW measurement". Fig. 10 shows the y-residuals of the crosses along the x-axis taken from a CW measurement done at the same time as the line measurement in Fig. 5. In principle these points should fall on top of the lines profile (a rotation around the origin is allowed due to possible small differences in θ_o). As can be seen from the figures the two profiles agree in some rough sense but the CW measurements do not reproduce the finer details like the curved distortion on each side of vertex and especially not near the vertex. The reason for this could be speculated on but in fact the measurements are radically different.

The angle between the slit and the straight line or fast track is ~0^o while in the CW measurements it varies between 30^o and 20^o. Another dubious point is the definition of the CW-pattern which is calibrated in one way (microscope measurements probably concerning only the central region of the crosses) and measured on SR in another (here the central regions of the crosses are excluded).

Application of line-residuals to beam track measurements

As mentioned the profile of the residuals in the line measurements could account for the distortion of curvature of beam tracks. This has been verified by making a correction in POOH where the residuals from the line measurements are used instead of those from the CW calibration. The result of this is shown in Fig. 11 where $\frac{1}{\rho}$ from THRESH is plotted after correction. As could be seen in this figure the residuals from LINES seem to correct fully the observed systematic effect.

An obvious shortcoming of this method is that we have only the possibility to measure in two orthogonal directions x and y, since we cannot turn the plate. The variation over 90^o can be seen from Fig. 12 which shows the residuals from the line in y-direction. Fig. 13 shows this line with corrections from the x-line and here we see that some of the structure still remains. On the other hand for real measurements the distortions is very important only for the fastest tracks and those are emitted in a narrow angular cone ($\theta \le tg \frac{<P_\perp>}{P}$, $<P_\perp> \sim 0.350$ GeV/c $P_\perp^{max} <1.0$ GeV/c), and within this the variation of the distortion is not expected to be significant.

As can be seen from Fig. 3, 4 and 11 the standard deviations in $\frac{1}{\rho}$ in SR measurements and the ENETRA measurements are of the same size ($\sigma \frac{1}{\rho} \sim 0.6\times10^{-5} cm^{-1}$). The average track length measured on the SR is 62 cm in the chamber while for the ENETRA-measurements (10 points/track) the corresponding length is 75 cm. In production measurements on ENETRA one usually puls only ~5 points/track. This implies that the SR gives considerably smaller random errors in production measurements compared to an ENETRA provided the measured track lengths are the same.

Hardware cause of the distortion

When investigating possible hardware causes for the described effects we turned the lens by 180^o. The measurements in terms of lines residual and beam track radius are shown in Figures 14-15. Here the picture is radically different and the distortion is much smaller. This indicates that the systematic distortion observed is of an optical nature and that it probably concerns both the lens and some mirror(s). One disadvantage with this lens position is that due to some strange reason it introduces a very disturbing astigmatic distortion in the autofiducial plane and we are afraid that this could ruin our autofiducial measurements.

Another reason for continuing the investigation of the original lens position is that we have a large sample of non-processed measurements waiting for the distortion problems to be solved.

Conclusion and future developments

The investigations presented in this paper are not complete and we will continue and elaborate more on some details in the nearest future.

The results obtained so far are however encouraging and we feel that with a combination of calibration from CW-measurements and systematic corrections along the lines presented here we are able to measure as high a momentum as 19 GeV/c in the 2 m BC with satisfactory results. This, according to our experience, is impossible with CW-calibration only, even if the CW-residuals are used.

Further on the random fluctuation or setting error obtained when systematic effects are removed; 1.8 μm on single points and 1 μm on master points is a surprisingly good number which seems to be well matched with the intrinsic setting error on real tracks in CERN 2 m HBC. This latter setting error seems to be caused by the bubble growth and is ~2.3 μm for "normal" flash delay[7].

Figure Captions:

Fig. 1 A typical result of SCALP calculations on one spiral of chicken walk measurements.

Fig. 2 Slit sensitivity
2 a: Full slit
2 b: Masked slit
2 c-d: Qualitative distortion of CW-crosses as a donsequence of uneven slit sensitivity.

Fig. 3 Distribution of $\frac{1}{\rho}$ from SR-measurements of non-interacting beam tracks (19 GeV/c protons).
3 a: Forward part.
3 b: Backward part.

Fig. 4 Same as Fig. 3 but measured with ENETRA.

Fig. 5 Residuals from fit of straight line measurements in beam direction.

Fig. 6 Residuals from fit of corrected straight line measurements. 12 spirals are superimposed.

Fig. 7 Projection of residuals from Fig. 6.

Fig. 8 Residuals from fit of straight line measurements. The line was oriented in "normal" position (beam direction).

Fig. 9 Same as Fig. 8 but the line rotated 180°.

Fig. 10 Y-residuals from SCALP on CW-crosses situated in the beam direction. Data taken at the same time as those of Fig. 5.

Fig. 11 Same as Fig. 3 but raw data corrected with residuals from line measurements.

Fig. 12 Residuals from fit of straight line measurements in SR Y-direction ($\perp$ beam)

Fig. 13 Same as Fig. 12, but data corrected with residuals from X-direction (same correction as in Fig. 6).

Fig. 14 Residuals from fit of straight line measurements with the SR-lens rotated 180°.

Fig. 15 Same as Fig. 3 but measured with the SR-lens rotated 180°.

References

1. Danish-Swedish Spiral Reader Project Status report and short systems description. Contribution to ESRS, Stockholm 1972.

2. Calibration plate for CERN LSD 11.12.66 and SRA 200.

3. SCALP, The Spiral Reader Calibration Programme, E.H. Eichman, CERN/D.Ph.II/69 -2.

4. POOH is the name of the off-line filter programme for the SR. The version used by DSSLP is derived from an early Stanford version and is described by E. Dahl-Jensen in a contribution to ESRS, Stockholm.

5. THRESH. A programme for the Geometrical Reconstruction of Curved tracks in Bubble Chambers, by W.G. Moorhead, CERN 60-33.

6. LINES a computer programme for the analysis of Spiral Reader measurements of straight lines. Contribution to ESRS, Stockholm 1972.

7. On optimized timing conditions for the CERN 2-meter hydrogen bubble chamber. A study of systematic and random errors. G. Ekspong, L.Voyvodic, J. Zoll. TC-report in draft.

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TOTAL SQUARE SUM   ,178+05 FOR4614, D,O,F,, RMS = 1,9689

RMS ERRORS AND NO OF POINTS USED FOR LEG 1 AND 2    1,94442 2440,    1,33924 2444,
NO, OF CROSSES MEASURED =  225 ,USED IN FIT =  167
MEAN ERROR OF EACH LEG =  ,373362,AND IN R AND THETA =   1,09164   ,397324

CALFIT RESULTS

PARAMETERS AND ERRORS

 -,2710+01   ,22+00   -,1389-03   ,33-05   -,2262-03   ,12-04   ,4350+01   ,51-01   -,4676+00   ,61-01

THE NEW PARAMETERS   ,45556+03   ,19438+01   ,14928+01   -,43499+01   ,66755+00

CONSTANTS FOR POOM (RCOUNT,TZERO/TCOUNT,RZERO/RCOUNT,XZERO,YZERO)
   ,14425+01        ,40095+05        ,31588+03        -,43499+01        ,66755+00

RESIDUALS AFTER THIS FIT
```

1	,00	,00	2	,00	,00	3	,00	,00	4	,00	,00	5	,00	,00	6	,00	,00
7	-4,73	-4,06	8	-3,20	-3,53	9	-3,03	-1,83	10	,00	,00	11	,00	,00	12	,00	,00
13	,00	,00	14	,00	,00	15	,00	,00	16	,00	,00	17	,00	,00	18	,00	,00
19	-2,98	-2,01	20	-3,23	-4,86	21	-5,88	-2,62	22	-3,09	-4,46	23	-1,83	-4,70	24	-,71	-1,83
25	2,04	-1,09	26	1,30	-4,66	27	1,88	-4,02	28	,00	,00	29	,00	,00	30	,00	,00
31	,00	,00	32	,00	,00	33	1,39	-2,18	34	,49	-3,60	35	-1,76	-3,90	36	-4,87	-4,37
37	-2,65	-5,17	38	-1,57	-5,85	39	-,91	-2,56	40	,48	-3,44	41	2,09	-2,57	42	2,71	-4,06
43	2,81	-3,09	44	,00	,00	45	,00	,00	46	,00	,00	47	,00	,00	48	2,40	-,97
49	2,65	-2,70	50	1,29	-4,66	51	-1,50	-4,21	52	-3,28	-3,69	53	-1,77	-4,33	54	,39	-4,45
55	,66	-4,22	56	1,30	-3,16	57	3,26	-2,65	58	2,58	-4,47	59	1,61	-6,16	60	,00	,00
61	,00	,00	62	,86	,71	63	3,78	-2,29	64	2,31	-1,50	65	1,45	-2,99	66	-1,69	-4,13
67	-3,32	-2,87	68	-1,53	-4,70	69	,07	-1,40	70	1,16	-2,70	71	1,52	-1,78	72	,94	-4,42
73	2,55	-3,65	74	1,24	-4,90	75	,00	,00	76	,00	,00	77	-,02	,93	78	1,16	-,06
79	2,27	-1,70	80	1,67	-2,43	81	-,08	-2,89	82	,36	-4,68	83	-,76	-2,41	84	,47	-2,37
85	,78	-1,31	86	3,83	-1,31	87	1,73	-3,67	88	3,22	-1,66	89	1,16	-2,66	90	,00	,00
91	-3,47	2,29	92	-1,08	1,26	93	-,64	-,18	94	,53	-1,45	95	-1,29	-1,70	96	-,33	-2,86
97	1,30	-3,23	98	-,38	-5,64	99	-,72	-1,80	100	-,83	-,80	101	1,50	,29	102	-,26	-1,69
103	-1,37	-2,04	104	-1,37	-2,42	105	-1,96	-3,46	106	-2,70	4,48	107	-,65	3,75	108	,67	1,95
109	2,55	1,59	110	3,31	,44	111	3,30	-1,96	112	1,15	-2,37	113	2,36	-1,71	114	-,02	,40
115	-1,00	,93	116	2,86	,03	117	8,86	-1,19	118	-,24	,17	119	-1,15	-,61	120	-,75	-1,10
121	-4,93	5,67	122	-1,72	3,86	123	-1,51	2,22	124	-,52	,83	125	-,85	-,88	126	,55	-1,56
127	,76	-4,67	128	3,87	-2,39	129	4,85	2,86	130	4,19	2,07	131	4,16	2,26	132	,61	,58
133	,01	1,16	134	-1,44	1,18	135	-,78	-,12	136	,00	,00	137	-6,71	3,09	138	-3,06	2,01
139	-1,40	1,40	140	-1,74	-,03	141	-1,22	-3,13	142	1,66	-2,78	143	4,26	-1,79	144	6,29	-,16
145	8,03	2,89	146	7,29	1,88	147	2,52	2,53	148	3,23	1,01	149	1,39	2,28	150	,00	,00
151	,00	,00	152	-7,86	4,26	153	-6,05	1,68	154	-4,11	1,60	155	-,56	,21	156	-1,15	-2,29
157	1,86	-3,76	158	3,46	-3,46	159	6,41	-2,15	160	7,99	1,27	161	6,26	5,24	162	5,06	4,66
163	1,29	4,58	164	1,29	4,56	165	,00	,00	166	,00	,00	167	-12,59	4,09	168	-8,64	3,58
169	-6,33	1,80	170	-2,97	-,58	171	-1,49	-,86	172	,76	-1,23	173	1,98	-1,79	174	4,56	-4,38
175	5,15	2,42	176	5,97	6,35	177	5,23	6,07	178	3,00	7,23	179	2,20	7,41	180	,00	,00
181	,00	,00	182	,00	,00	183	-9,64	1,64	184	-7,17	1,49	185	-5,16	2,05	186	-5,08	-1,03
187	-,61	-1,06	188	1,39	1,19	189	3,75	1,67	190	7,10	-,00	191	5,14	6,25	192	5,80	7,33
193	6,06	9,45	194	,00	,00	195	,00	,00	196	,00	,00	197	,00	,00	198	,00	,00
199	-10,72	1,02	200	-6,87	1,67	201	-6,67	-1,81	202	-3,02	,16	203	-1,39	,31	204	1,73	2,04
205	4,07	1,28	206	4,61	5,71	207	,00	,00	208	,00	,00	209	,00	,00	210	,00	,00
211	,00	,00	212	,00	,00	213	,00	,00	214	,00	,00	215	,00	,00	216	,00	,00
217	-3,34	1,77	218	-1,22	-,20	219	1,63	3,32	220	,00	,00	221	,00	,00	222	,00	,00
223	,00	,00	224	,00	,00	225	,00	,00									

```
CORRELATION MATRIX

 2 -,00
 3  ,95 -,00

 4 -,00 -,00 -,00
 5  ,00  ,00  ,00 -,00
      1    2    3    4

NO, OF CROSSES MEASURED = 225   USED IN FIT = 167
CHISQUARE FOUND =   ,76853+04
NXP AND NYP =     3    2

RMS RESIDUAL IN R AND THETA AFTER FIT     1,90    2,82

HIGHEST RESIDUAL IN X =-12,59  AT CROSS 167
                 IN Y =  9,45  AT CROSS 193

HIGHEST RESIDUAL FOUND =   12,6
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Fig. 1

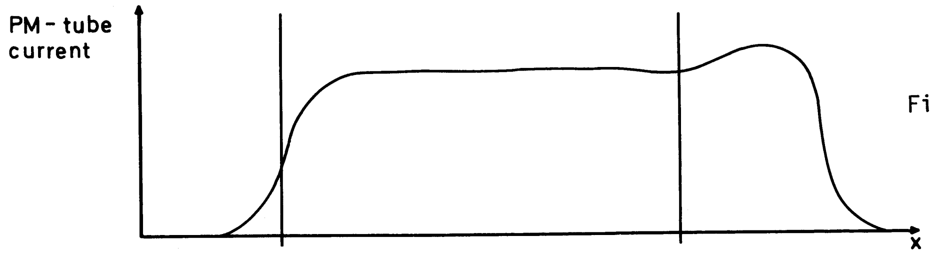


Fig. 2a

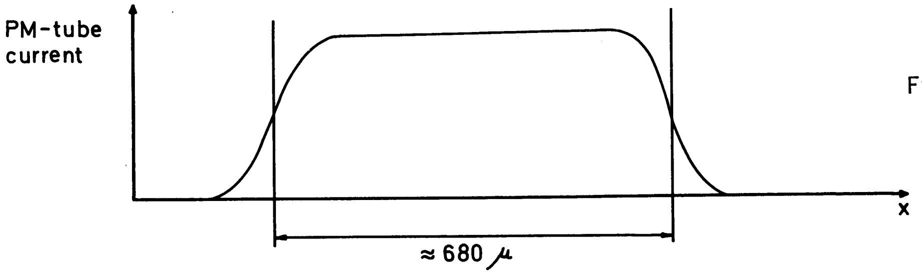
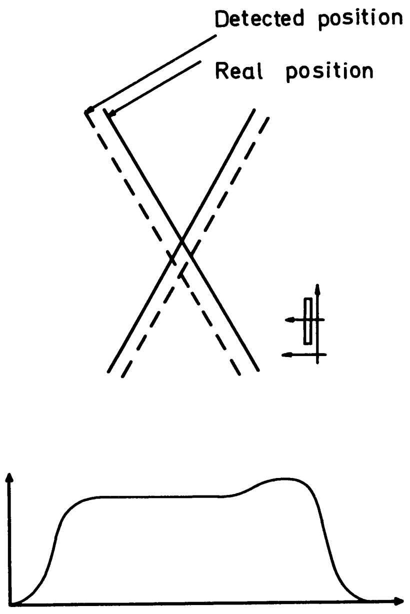


Fig. 2b



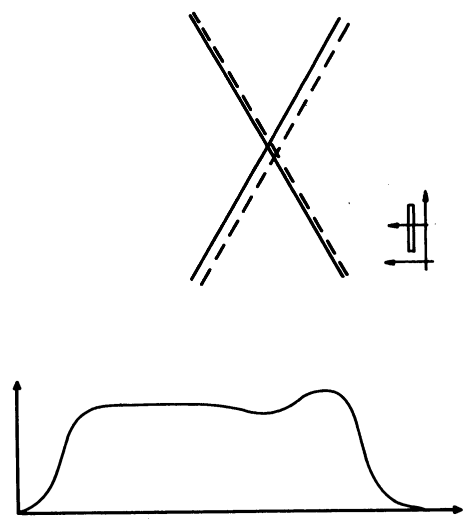


Fig. 2c

Fig. 3d

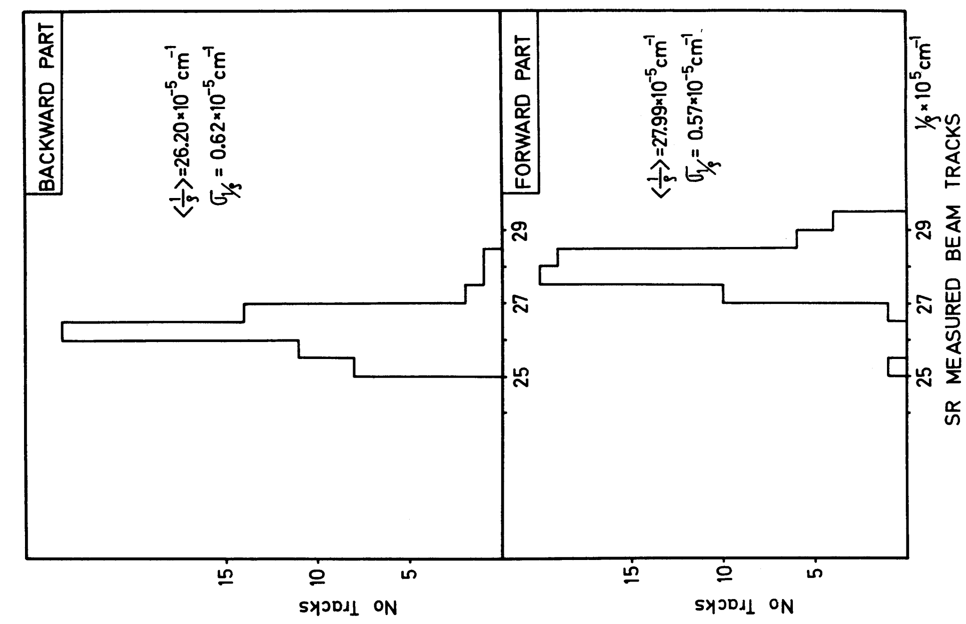

BACKWARD PART
<1/ς>=26.20×10⁻⁵cm⁻¹
σ1/ς = 0.62×10⁻⁵cm⁻¹
FORWARD PART
<1/ς>=27.99×10⁻⁵cm⁻¹
σ1/ς = 0.57×10⁻⁵cm⁻¹
No Tracks
15
10
5
25
27
29
1/ς ×10⁵cm⁻¹
SR MEASURED BEAM TRACKS

Fig. 3

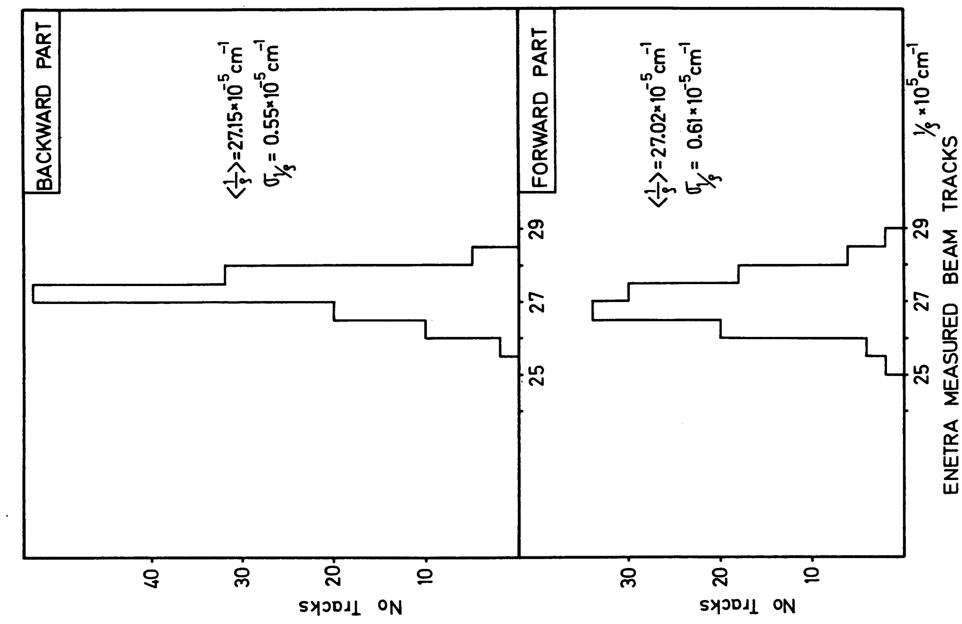

BACKWARD PART
<1/ς>=27.15×10⁻⁵cm⁻¹
σ1/ς = 0.55×10⁻⁵cm⁻¹
FORWARD PART
<1/ς>=27.02×10⁻⁵cm⁻¹
σ1/ς = 0.61×10⁻⁵cm⁻¹
No Tracks
40
30
20
10
25
27
29
1/ς ×10⁵cm⁻¹
ENETRA MEASURED BEAM TRACKS

Fig. 4

Residuals from fit
of straight line
measurements

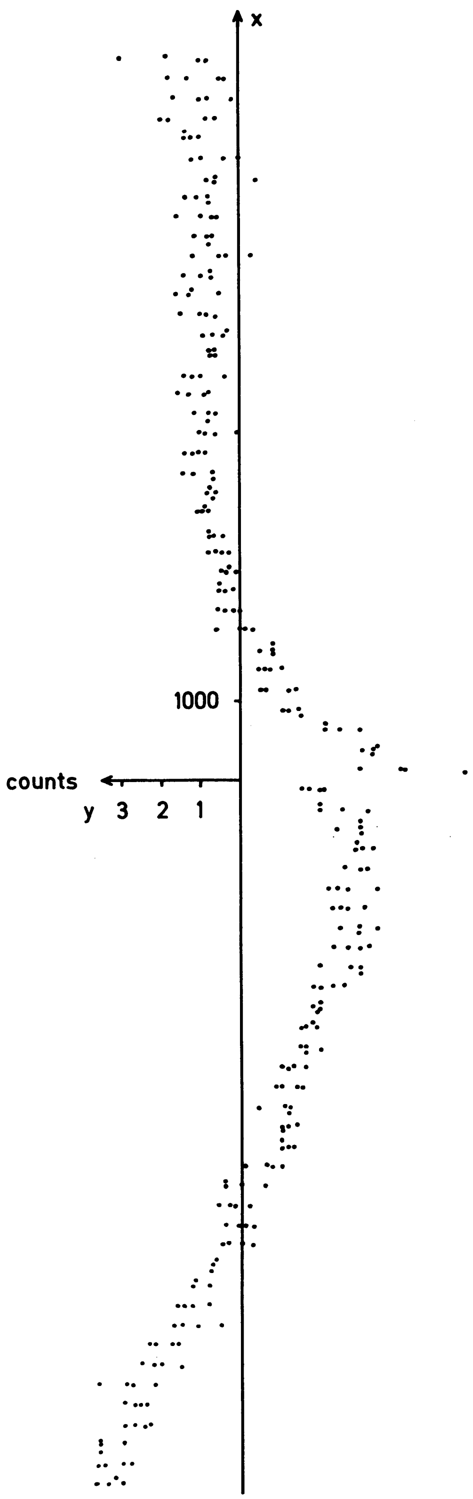


Fig. 5

Residuals from fit of
"corrected" straight
line measurements

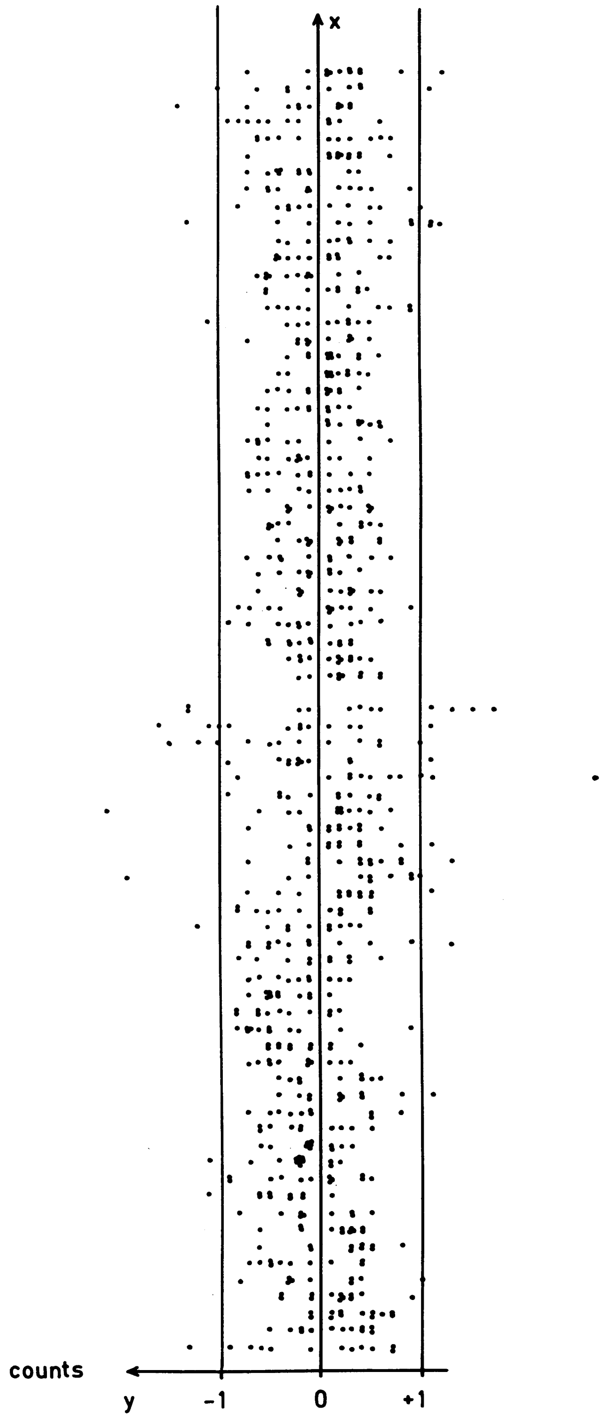


Fig. 6

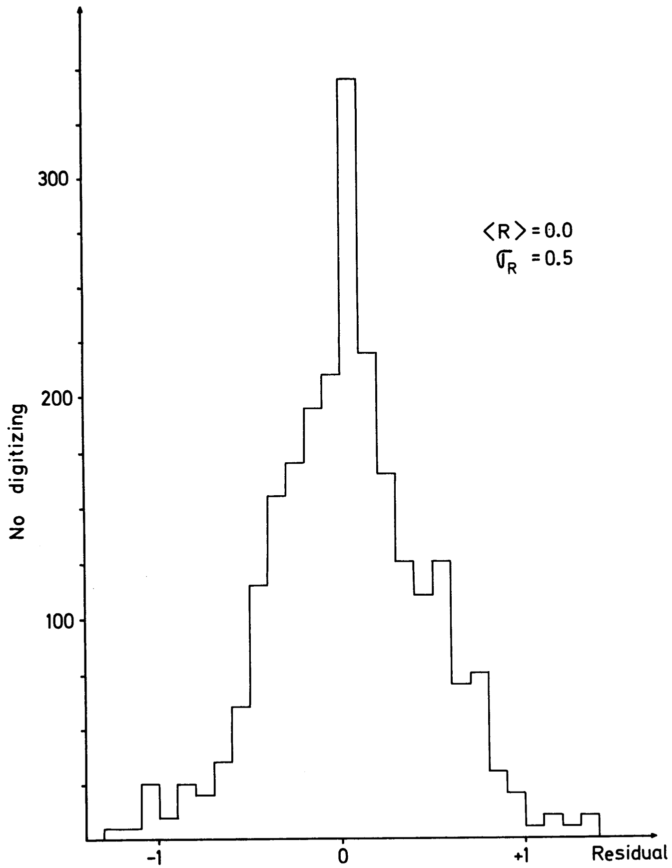

No digitizing
300
200
100
-1
0
+1
Residual
⟨R⟩ = 0.0
σ_R = 0.5

Fig. 7

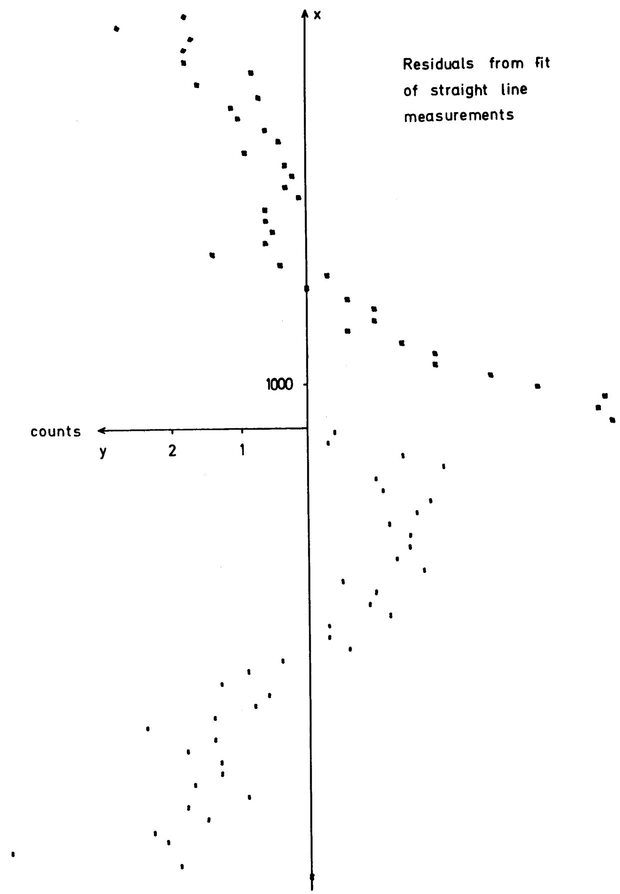

x
Residuals from fit
of straight line
measurements
1000
counts
y
2
1

Fig. 8

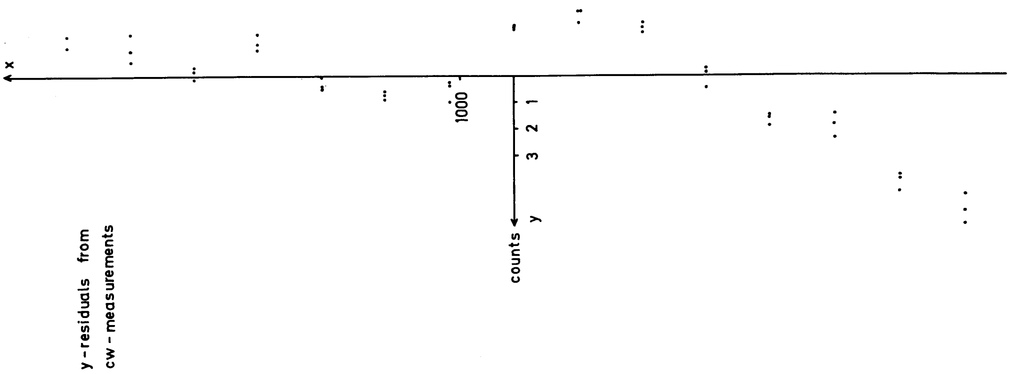

y-residuals from
cw-measurements
x
1000
1 2 3
y
counts

Fig. 10

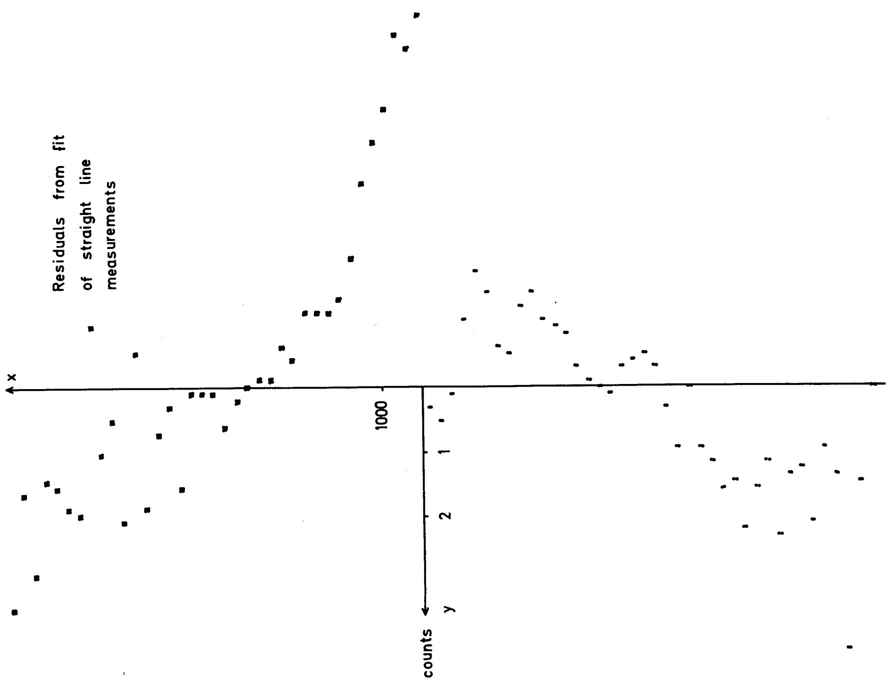

Residuals from fit
of straight line
measurements
x
1000
1
2
y
counts

Fig. 9

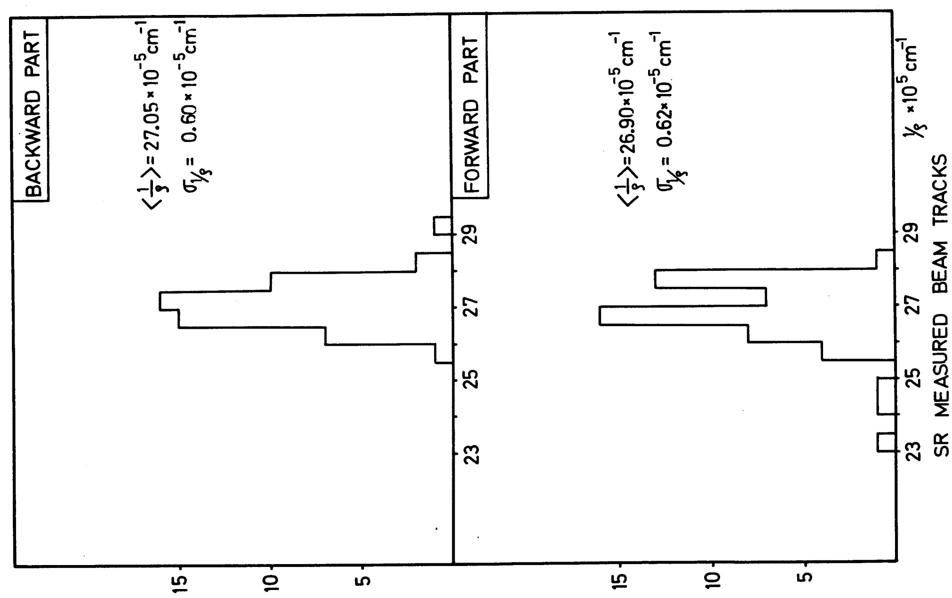

BACKWARD PART
$\langle \frac{1}{\rho} \rangle = 27.05 \times 10^{-5} cm^{-1}$
$\sigma_{1/\rho} = 0.60 \times 10^{-5} cm^{-1}$
FORWARD PART
$\langle \frac{1}{\rho} \rangle = 26.90 \times 10^{-5} cm^{-1}$
$\sigma_{1/\rho} = 0.62 \times 10^{-5} cm^{-1}$
No Tracks
15
10
5
23
25
27
29
$1/\rho \times 10^{5} cm^{-1}$
SR MEASURED BEAM TRACKS

Fig. 11

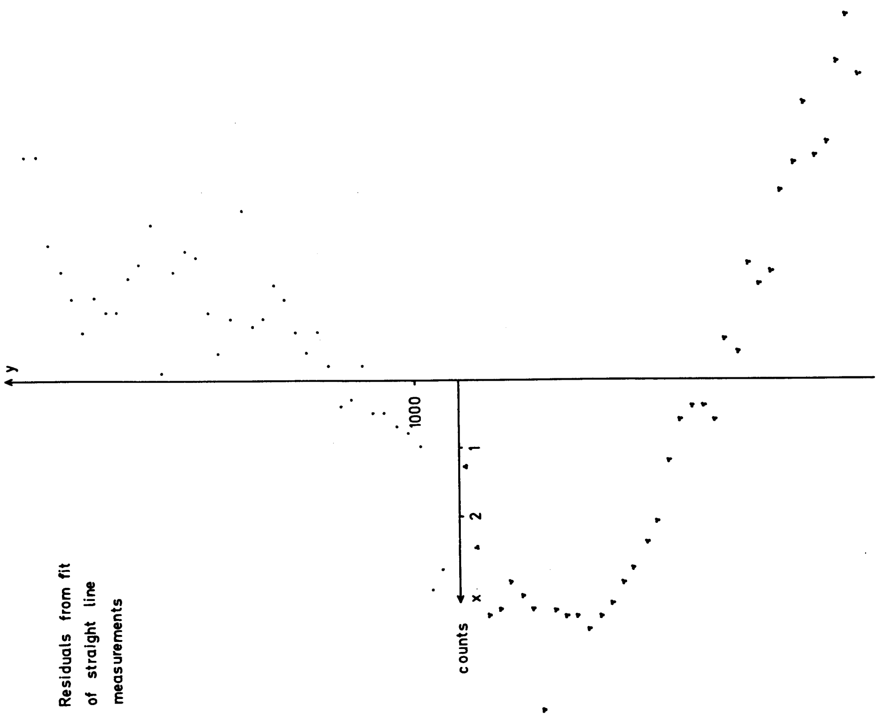

Residuals from fit
of straight line
measurements
counts
1000
1
2
x
y

Fig. 12

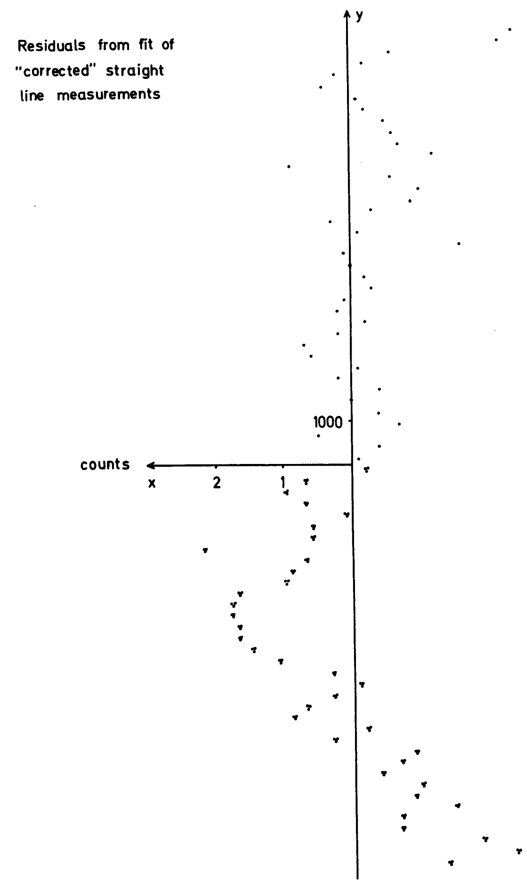

Residuals from fit of
"corrected" straight
line measurements
y
1000
counts
x
2
1

Fig. 13

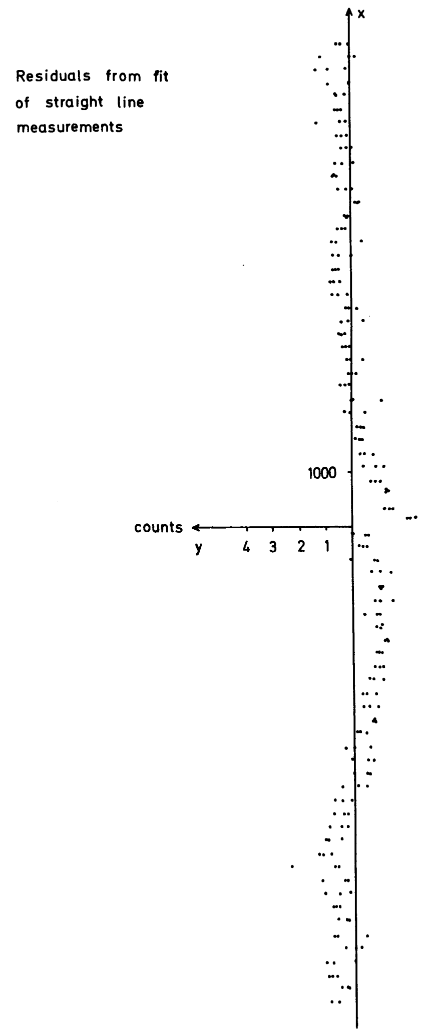

Residuals from fit
of straight line
measurements
x
1000
counts
y
4 3 2 1

Fig. 14

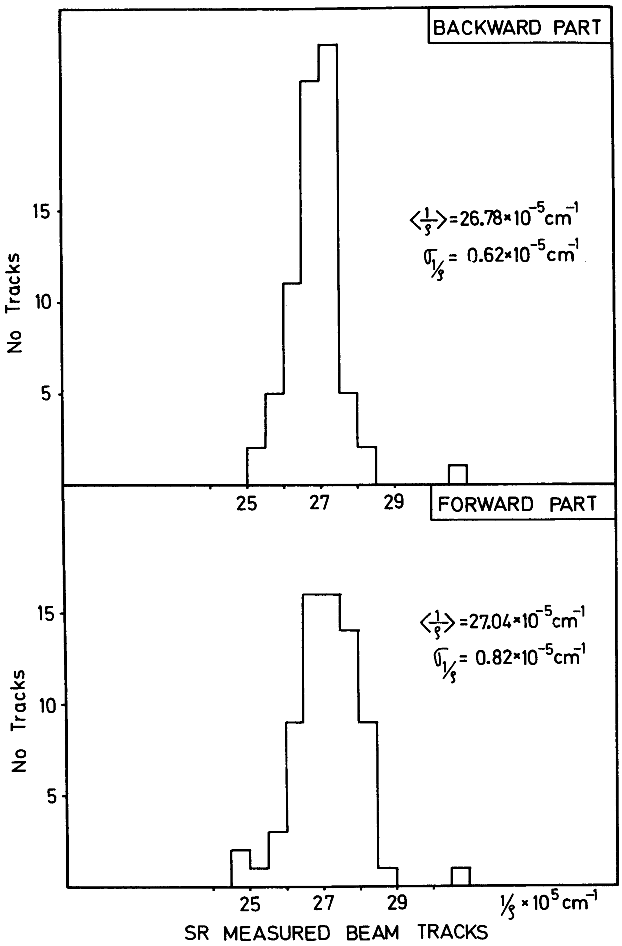

BACKWARD PART
$\langle \frac{1}{\rho} \rangle = 26.78 \times 10^{-5} cm^{-1}$
$\sigma_{1/\rho} = 0.62 \times 10^{-5} cm^{-1}$
No Tracks
15
10
5
25
27
29
FORWARD PART
$\langle \frac{1}{\rho} \rangle = 27.04 \times 10^{-5} cm^{-1}$
$\sigma_{1/\rho} = 0.82 \times 10^{-5} cm^{-1}$
No Tracks
15
10
5
25
27
29
$1/\rho \times 10^{5} cm^{-1}$
SR MEASURED BEAM TRACKS

Fig. 15