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MEASUREMENT OF BEAM MOMENTUM GAIN IN ACCELERATING SECTIONS ACS 25,26

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1. Introduction

The beam momentum after ACS 25,26 is calculated from the beam displacement at UMA 27 due to the vertical deflection by the steering coil DQLA 271. Three experiments are analyzed. Scaling to a klystron power of 35 MW yields 0.11 GeV/c as the maximum possible momentum gain across these two LIL sections fed by RF station 25. A comparison with the design values is given.

2. Experiment I

Run 31.7.86; logbook Vol. II, p. 196,197. $T_{25} = 29.8^{o}C$(SP).
U_c(PKI25) = 2.32V (no ADE filter).

In the experiment the two quadrupoles QLA 271, QLA 272 between end of ACS 26 and UMA 27 were on. The first one is vertically defocusing, the second is vertically focusing.

Using thin lens approximation, neglecting the influence of QLA 271 and representing the deflection by the steering coil DQLA 271 in QLA 271 by a vertical kick in the centre of QLA 271, yields for the displacement at UMA 27 per unit current in the coil

$$\frac{dy_2}{dI} = \left(L_1 + L_2 - \frac{L_2 L_1}{a_f p}\right)\frac{a_d}{p} \qquad (1)$$

where

$f = a_f \cdot p$ focal length of QLA 272

$dy_1' /dI = a_d/p$ deflection angle of DQLA 271 for 1A

Figure 1a shows the simple model on which (1) is based. Fig. 1b shows the expected behaviour indicating that a given $dy_2/dI > 0$ can be produced at two momenta. Thus, if the beam momentum is close to the value where dy_2/dI is maximum, a unique determination of p becomes impossible. The geometry is taken from the MAD data base[1].

Figure 2a shows the correct thick lens model. The gradient length is taken from magnetic measurements (see forthcoming note by D. Warner). We put the DQLA271 bending length equal to the gradient length of QLA271. Appendix I gives the derivation of the formula used, and Fig. 2b the calculated $dy_2/dI = f(p)$. The parameters are

QLA 271 I = 7.99 A (CCV)
QLA 272 I = 9.60 A (CCV)
} d (GL)/dI = 0.0549 T/A [2]

DQLA 271 $a_d = 3.42 \cdot 10^{-5} \ \frac{\text{rad}}{\text{A}} \cdot \frac{\text{GeV}}{\text{c}}$ [2]

Table I gives the data. The first column defines the power of klystron 25. The value $\Delta y_2/\Delta I$ is obtained by a least-square fit of a straight line to the data y_2 versus I. Each y_2 is an average over 5 digital read-outs which are themselves the average over many individual measurements. The current at UMA 27 was constant indicating that no beam loss occurred due to the deflection. The momentum p is obtained by solving Eq. (4) of Appendix I.

TABLE I, Data first experiment, Data set I.1

U_c (PKI25) V	ϕ_{25} degr.	$\Delta y_2/\Delta I$ mm/A	p MeV/c
2.32	7	0.182	96
2.32	27	0.173	103
2.32	- 13	0.205	81
2.32	47	0.263	60

Appendix II shows that the buncher W provided a beam of 4 MeV/c. By the way, our measurements of dissipated power in the buncher are not yet very consistent.

Fig. 3 shows the momentum gain Δp = p-4MeV/c versus phase of RF25. The points should lie on a cosine

$$\Delta p = \hat{\Delta p} \cos (\phi - \hat{\phi}) \qquad (2)$$

The point at 47° was elimated because too low in energy.

a) Fit I.1

Using each combination of two data points to calculate $\hat{\Delta p}$ and $\hat{\phi}$ yields Table II. Since the spread in the resulting $\hat{\Delta p}$ and $\hat{\phi}$ is small, all three points are indeed close to a cosine. The dashed curve in Fig. 3 is drawn using the average values $\hat{\Delta p}$ = 98 MeV/c, $\hat{\phi} = 26^o$.

TABLE II, Parameters of data pairs

ϕ_1 degr.	ϕ_2 degr.	$\hat{\Delta p}$ MeV/c	$\hat{\phi}$ degr.
7	27	99	29
7	- 13	96	23
27	- 13	99	26
average		98	26

Fit I.1

b) Fit I.2

Using the usual least-square method to fit (2) to the data points yields

$$\hat{\Delta p} = 98 \text{ MeV/C and } \hat{\phi} = 26^o$$

identical to the result of the first "fit".

3. Experiment II

Run 13.8.86, logbook Vol. II, p. 222/224. All data taken with U_c(PKI25)= 2.1V (ADE filter in). $T_{25} = 29.8^oC$.

3.1 QLA 271, QLA 272 OFF

Table III gives the data. The second column states the values obtained from the extreme deflections, the third column the least-square fit. The agreement is good. The momentum p is obtained with the values of the 3rd column from

$$\frac{dy_2}{dI} \left(\frac{mm}{A}\right) = (L_1 - L_2) \cdot \frac{a_d}{p} = 24.3 / p \left(\frac{MeV}{c}\right) \quad (3)$$

and Δp by subtracting the input momentum 4 MeV/c.

TABLE III, Data second experiment QLA OFF, Data set II.1

ϕ_{25} degr.	$\Delta y_2/\Delta I$ mm/A	$\Delta y_2/\Delta I$ mm/A	p MeV/c	Δp MeV/c
- 31	0.592	0.594	40.9	36.9
- 1	0.355	0.355	68.4	64.4
0	0.340	0.342	71.1	67.1
25	0.255	0.255	95.3	91.3
41	0.240	0.238	102	98.1
41	0.240	0.244	99.6	95.6
55	0.257	0.254	95.7	91.7
86	0.382	0.383	63.4	59.4

Fig. 4 shows $\Delta p = f(\phi_{25})$.

Using again least-square fitting of (2) to the data yields Table IV.

TABLE IV, Results of Fits

Fit	$\hat{\Delta p}$ MeV/c	$\hat{\phi}$ degr.	Comments
II.1.1	93	39	all points used
II.1.2	93	41	- 31° excluded
II.1.3	96	41	only the 4 points above 90 MeV/c

Fit II.1.3 is shown in Fig. 4.

3.2 <u>QLA 271, QLA 272 ON</u>

These data were taken to check the experiment I.

TABLE V, Data second experiment QLA ON, Data set II.2

ϕ_{25} degr.	$\Delta y_2/\Delta I$ mm/A	$\Delta y_2/\Delta I$ mm/A	p MeV/	Δp MeV/c
- 1	0.200	0.200	84	80
41	0.180	0.180	97	93
81	0.222	0.223	73	69

Fit II.2.1

Method of fit I.1 yields Table VI. Since the spread in the resulting $\hat{\Delta p}$, $\hat{\phi}$ is large, the points are not very close to a cosine.

TABLE VI, Parameters of data pairs

ϕ_1 degr.	ϕ_2 degr.	$\hat{\Delta p}$ MeV/c	$\hat{\phi}$ degr.
- 1	41	95	32
- 1	81	99	35
41	81	93	39
mean		95	35

Fit II.2.1

The dashed curve in Fig. 5 corresponds to the fit the last line of Table VI.

Fit II.2.2

Fitting a cosine to the data of Table V yields

$$\hat{\Delta p} = 96 \text{ MeV/c and } \hat{\phi} = 35^\circ$$

which is within the spread of values of Table VI.

3. Experiment III

Run 28.8.86, logbook vol. III, p.5, U_c(PKI25) = 2.04V (ADE filter in).

In this experiment the maximum momentum gain versus temperature T_{25} was sought. Momentum gain versus phase at four different temperatures was measured. Table VII shows the results. The third column gives the deflection for unit current obtained from fitting a straight line to the data points. The fourth column displays the calculated momentum gain shown in Fig. 6 versus phase. The last two columns give the parameters of the fitted cosine functions ; the fits are indicated in Fig. 6 by dashed lines.

The notorious instability of the phase control system is apparent from comparison of Fig. 6a and 6e which should be identical but display a phase drift of 15° ! This could either be a drift in ϕ_{03} or ϕ_{25}.

Figure 7 gives $\hat{\phi}$ versus T_{25}. Table VII and Fig. 6 give the points in the order they were measured. Fitting a straight line through the three points measured first yields -7°/1°C. The fit through all points gives -13°/1°C.

Table VII, Data of third experiment, OLAs off, Data set III

$T_{25}(SP)$ °C	φ_{25} degr.	$\Delta y_2/\Delta I$ mm/A	Δp MeV/c	$\hat{\Delta p}$ MeV/c	$\hat{\varphi}$ degr.	Fit
29.8	193	0.225	104	100	196	III.1
	224	0.270	86.0			
	162	0.285	81.3			
	208	0.240	97.3			
28.8	207	0.225	104	103	207	III.2
	238	0.265	87.7			
	177	0.260	89.5			
27.8	193	0.245	95.2	103	210	III.3
	222	0.225	104			
	252	0.303	74.4			
	208	0.220	106			
30.8	208	0.255	91.3	104	174	III.4
	228	0.370	61.7			
	188	0.235	99.4			
	167	0.230	102			
	148	0.250	93.2			
	128	0.300	77.0			
	172	0.235	99.4			
29.8	200	0.245	95.2	103	181	III.5
	170	0.230	102			
	140	0.300	77.0			
	180	0.220	106			

The measurements with ACS 35 and 36 by A. Bellanger, P. Brunet and R. Riche (2.7.86, logbook Vol. II, p.115) gave the value of 8.7°/1°C. The measurement with ACS 27, 28, 29, 30 by B. Frammery, I. Kamber and K. Hubner (16.7.86, logbook Vol. II, p.154) gave 6.4°C/1°C but cannot be relied upon because the beam energy was measured at the end of the linac where it is also influenced by LIPS 31 which is unfortunately in the same cooling circuit as these sections.

The expected value is -9°/1°C according to D. Warner. P. Brunet also worked out a similar value. The positive sign of the measured $\Delta\phi/\Delta T$ probably is due to a sign error in the control system.

The momentum gain Δp at optimum phase shown in Fig. 8 seems fairly independent of temperature if the 100 MeV/c point is disregarded. This would agree with calculations (see forthcoming note by D. Warner). On the contrary, the measurements with ACS 35, 36 cited above indicate a clear maximum with a drop of about 3% for $\Delta T = \pm 1°C$.

5. Discussion

In order to estimate the energy gain at a klystron output power of 35 MW, to which we normalize the results, the RF power used with the different data sets is needed. Knowing U_c (PK125) the calibration curve [3] shown in Fig. 9 can be used. Since the ADE filter (0.48 db insertion loss) was mounted prior to the second experiment, the correcte U_c^* (PK125) apply. The calibration curve was made without ADE filter.

The results are given in Table VIII indicating also $\hat{\Delta p}$ for 35 MW in the last column.

TABLE VIII, Summary of results and $\hat{\Delta p}$ at 35 MW

Dataset	Fit degr.	$\hat{\Delta p}$ MeV/c	U_c (PKI25) mm/A	U_c^* (PKI25)	P MW	$\hat{\Delta p}$ (35MW) MeV/c	Comment
I. 1	I. 1	98	2.32	-	27.5	111	QLAs on
	I. 2	98	"	-	"	111	"
II.1	II.1.1	93	2.10	2.24	26	108	QLAs off
	II.1.2	93	"	"	"	108	"
	II.1.3	96	"	"	"	111	"
II.2	II.2.1	95	"	"		110	QLAs on
	II.2.2	96	"	"		111	"
III	<III>	103	2.04	2.18	24.4	123	QLAS off

Averaging over all measurements yields $\hat{\Delta p}$ = 112 MeV/c at 35 MW. It is not understood why the last experiment gave a value 12% higher than the mean. A reading error of U_c ? Although this inconsistency exists and the calibration (Fig. 9) is not perfect, it is interesting to compare with the design aim of 60 MeV per section for 15 MW input[4,5].

Scaling to 15 MW at section input and taking into account the mean attenuation of 3.37 db between klystron and section 25,26 at 2988.55 MHz[6] yields

$$\Delta W \simeq \frac{112}{2} \sqrt{\frac{15}{35/2.17}} = 54 \text{ MeV/section}$$

which is 10% below design value. Certainly, more careful measurements will be needed before a definitive comparison can be made. For those a stable phasing system and a better klystron power measurement are prerequisite.

APPENDIX I

If a dipole field B_d deflecting upwards is superimposed on a vertically defocusing quadrupole field, the field can be simulated by displacing a pure quadrupole downwards by

$$\Delta y_q/\Delta I = (B_d . L_d)/(\delta Bq/\delta y)L_q \qquad (1)$$

where $B_d.L_d$ is the field integral at unit current in the deflecting coil. The effective length of the quad is L_q. The trajectory after the quad relative to the LIL axis is

$$y_1 = (d_{11}-1)\Delta y_q$$

$$y_1' = (d_{21})\Delta y_q \qquad (2)$$

At UMA 27

$$\vec{y}_2 = M_{12}\vec{y}_1 \qquad (3)$$

where M_{12} is the transfer matrix from end quad QLA 271 to UMA 27 comprising the focusing quad QLA 272. The matrix elements are called d_{ik} and f_{ik} for defocusing and focusing quad. The final formula is

$$\frac{\partial x_2}{\partial I} = \frac{\Delta y_q}{\Delta I}\Big[(f_{11} + L_2 f_{21})(d_{11} - 1) + \qquad (4)$$

$$+ (L_1 f_{11} + f_{12} + L_1 L_2 f_{21} + L_2 f_{22}) d_{21}\Big]$$

APPENDIX II

Momentum at exit buncher w

a) from klystron output power

U_c (PKI03) = 1.9 V box C output

P_c = 46.4 mV box C input

Attenuation= 82.9 db coupler + attenuator + cable

P = 1.21 MW

Use Fig. 4 of LPI Note 86-15 (theor. value) to get

ΔW = 3.70 MeV energy gain

b) from loop signal

U_c (LBNW) = 1.8 V

P_c = 42.2 mw

Att = 73.9 db

P = 1.05 Mw

ΔW = 3.46 MeV

Taking the average ΔW and adding 60 keV for the input energy yields

W = 3.6 MeV

and

p = 4.1 MeV/c

REFERENCES

1) J.C. Godot, LIL geometry, MAD run July 1986

2) D.J. Warner, Calibration and Nominal settings for LIL-W Transport Elements, March 1986

3) J.P. Perrine, MDK 25 logbook 17.1.1986, dashed curve fitted by eye.

4) LEP Design Report, Vol. I, p.10 (1983)

5) CERN-LAL, Linear Accel.Conf., Seeheim (1984), 288.

6) SPINNER, measurement 6.12.1985

Distribution

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Thin lens model

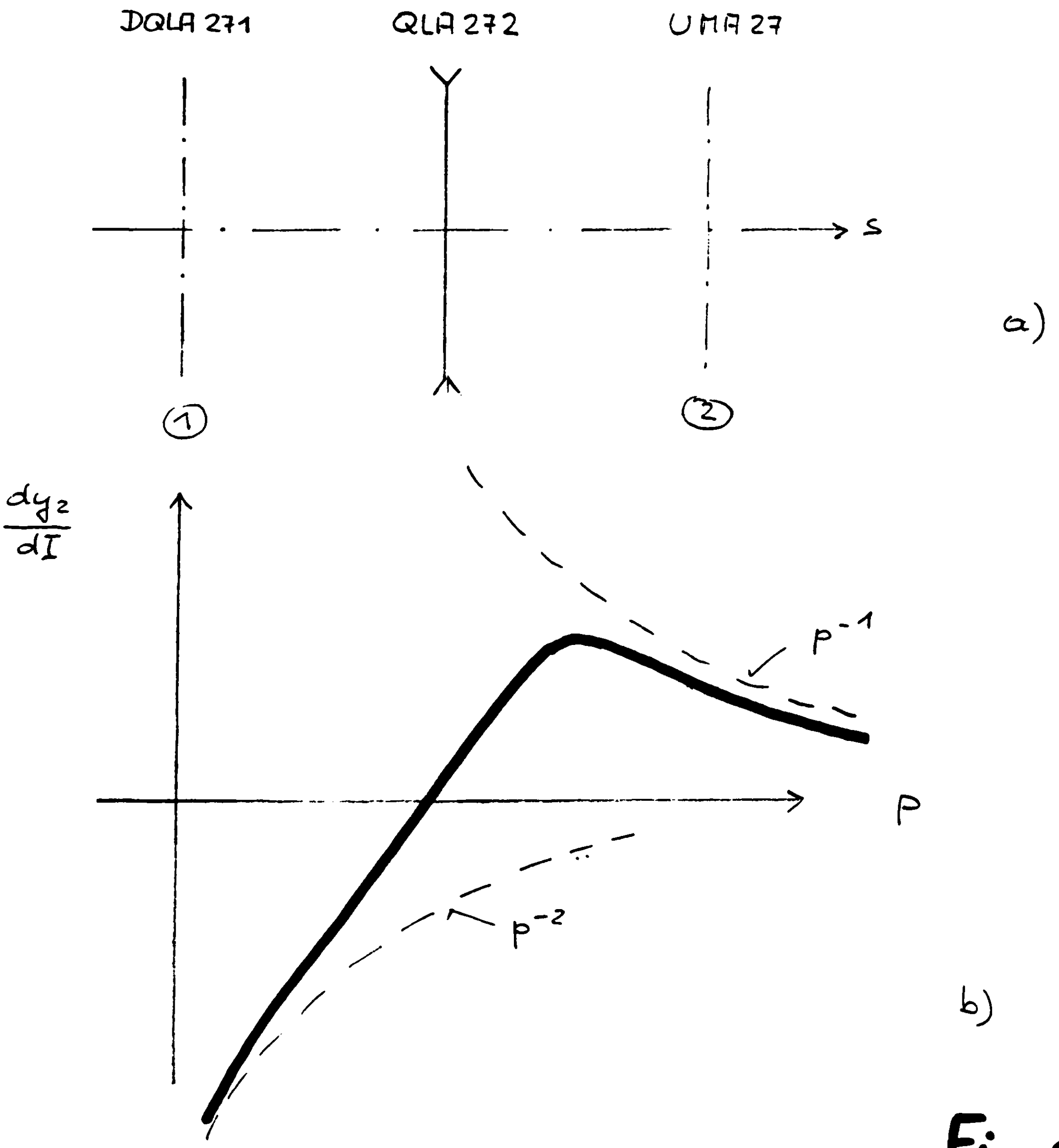


Fig. 1

Thick-lens model

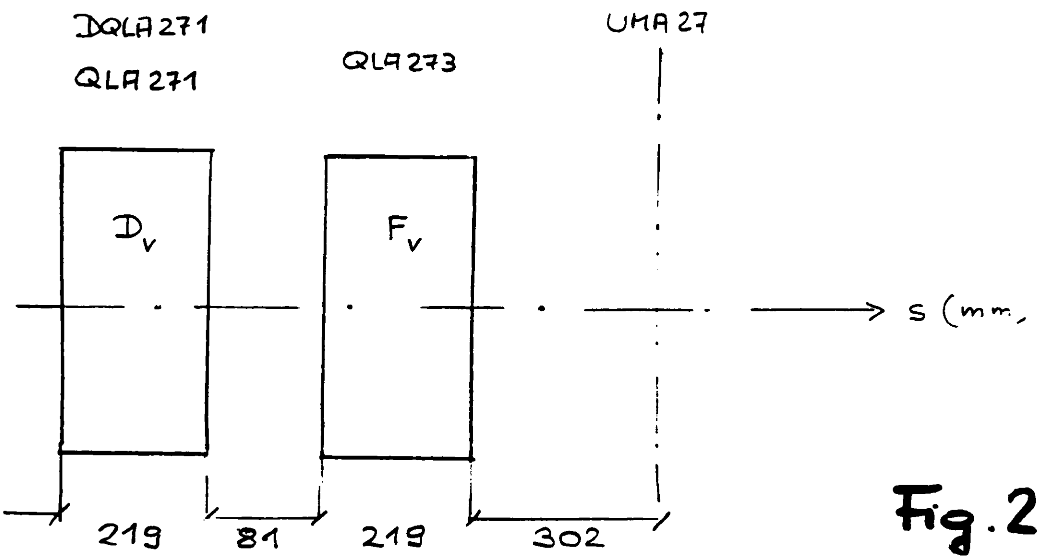


Fig. 2a

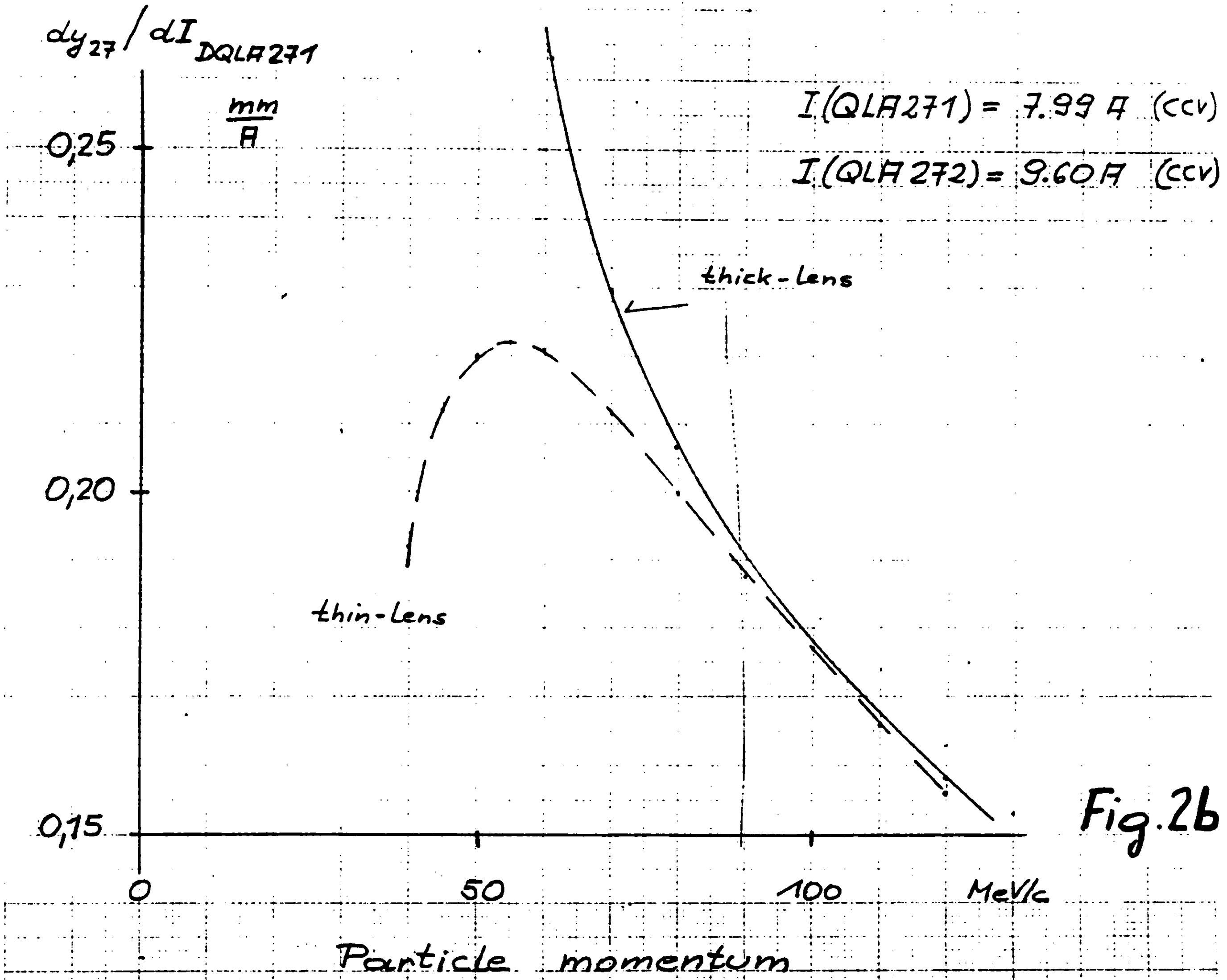

$dy_{27}/dI_{DQLA271}$
mm/A
0,25
0,20
0,15
I(QLA271) = 7.99 A (ccv)
I(QLA272) = 9.60 A (ccv)
thick-lens
thin-Lens
0
50
100
MeV/c
Particle momentum

Fig. 2b

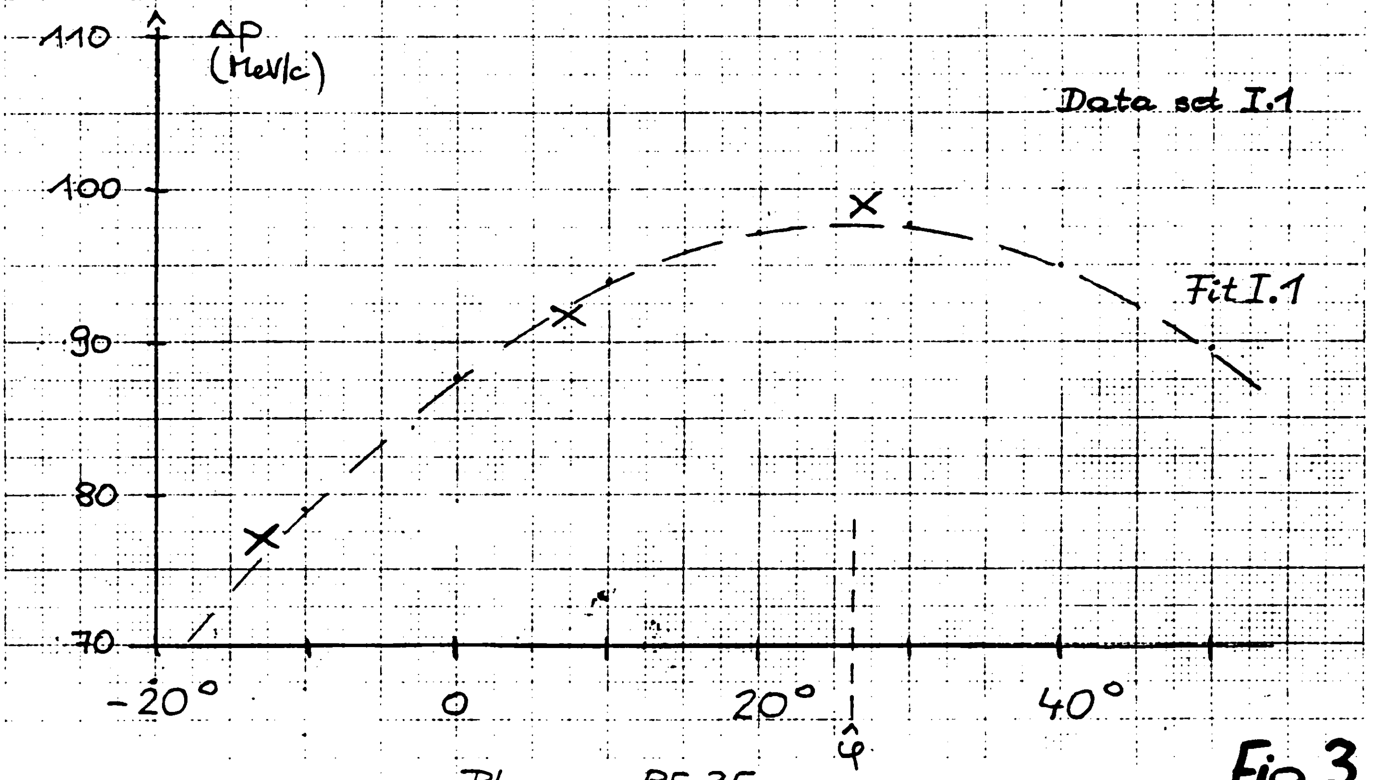

Δp (MeV/c)
110
100
90
80
70
Data set I.1
Fit I.1
-20°
0
20°
40°
$\hat{\varphi}$
Phase RF 25

Fig. 3

(×)

Acceleration in ACS 25,26 versus RF phase 25

Data from 13.8.86

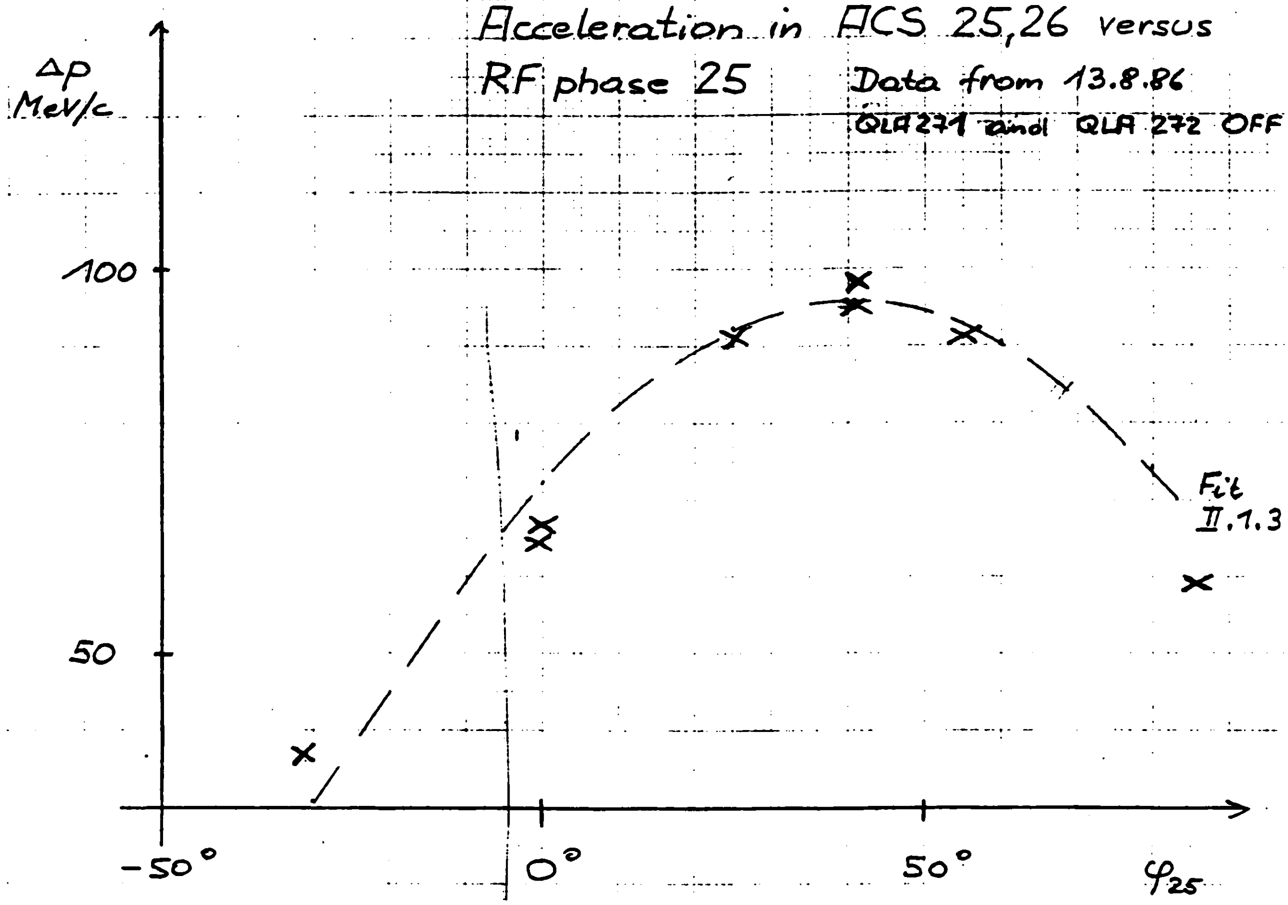


Fig. 4

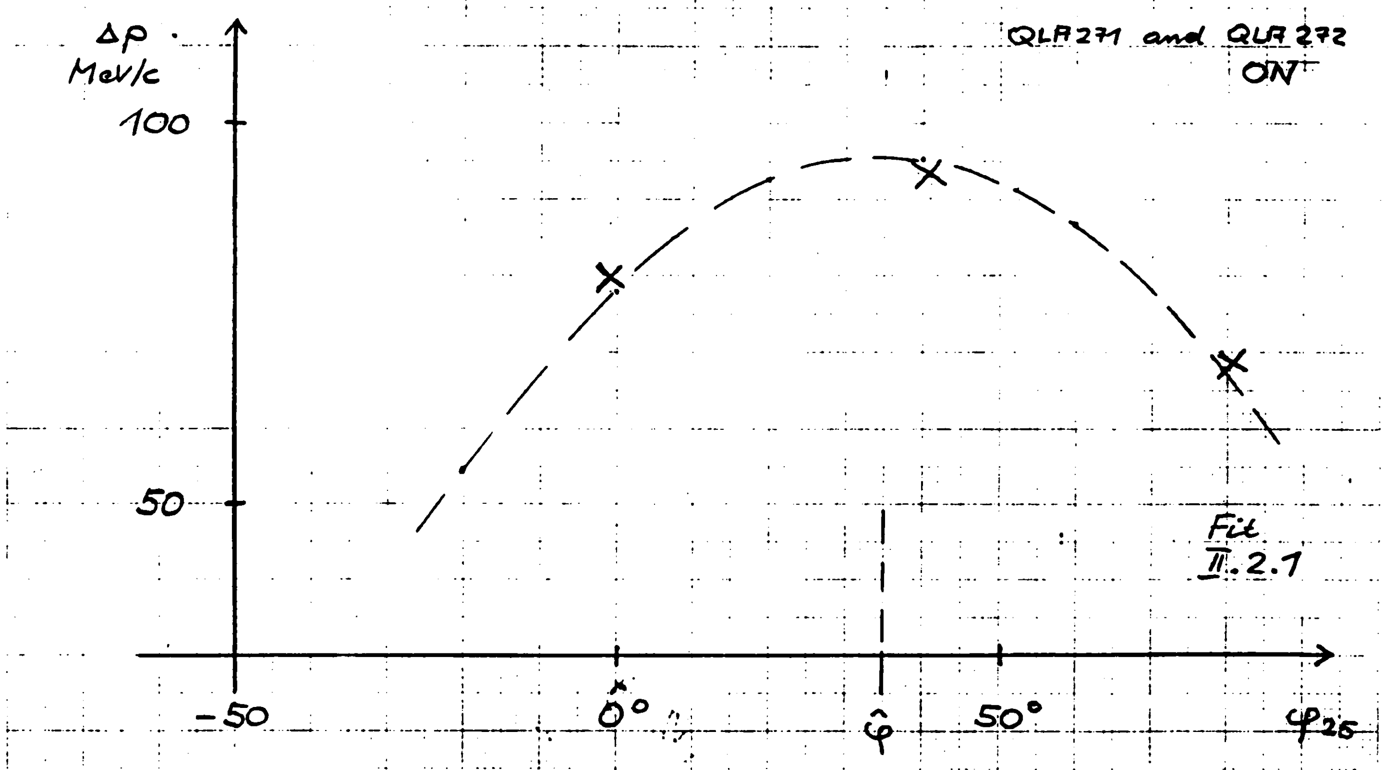
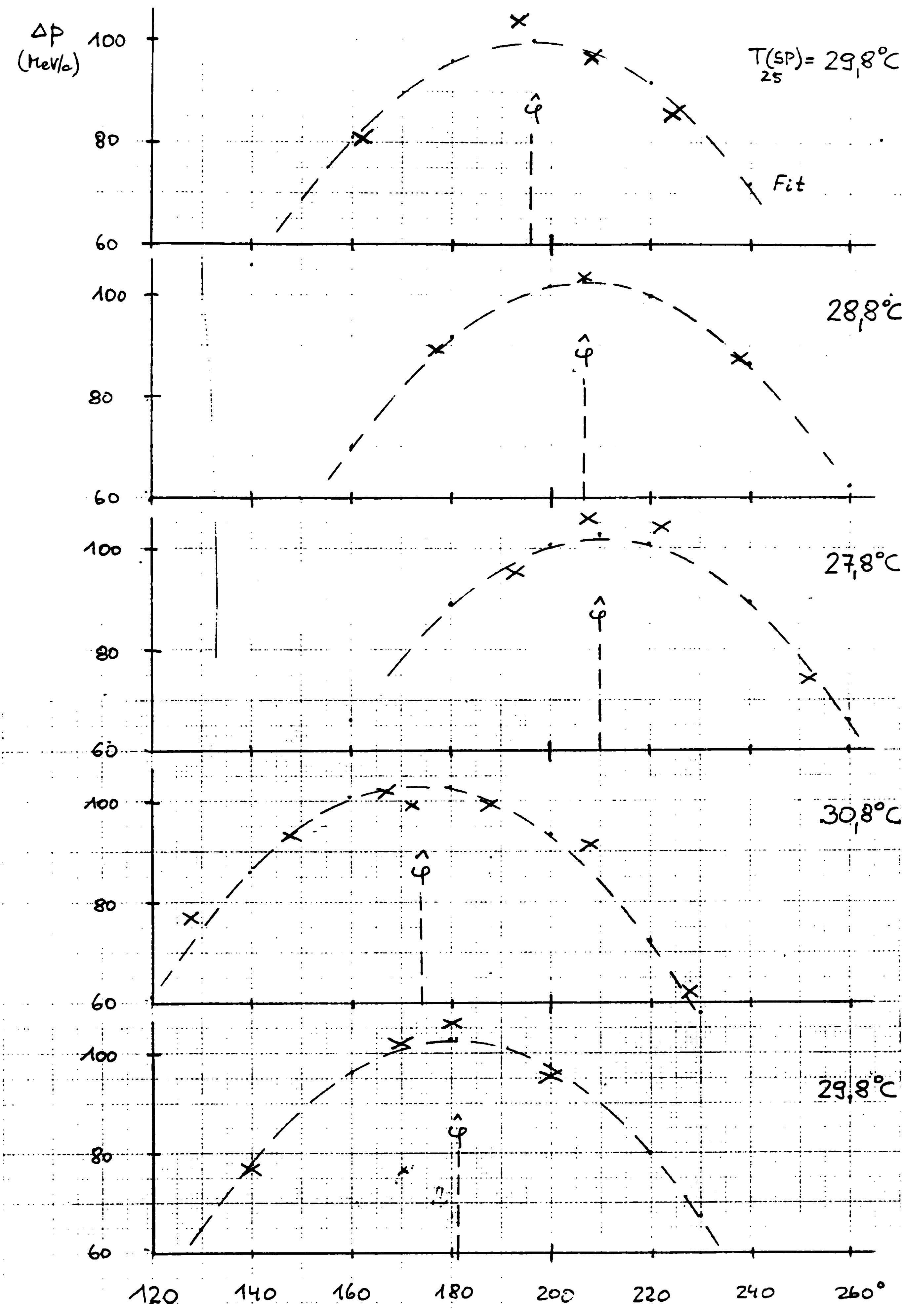
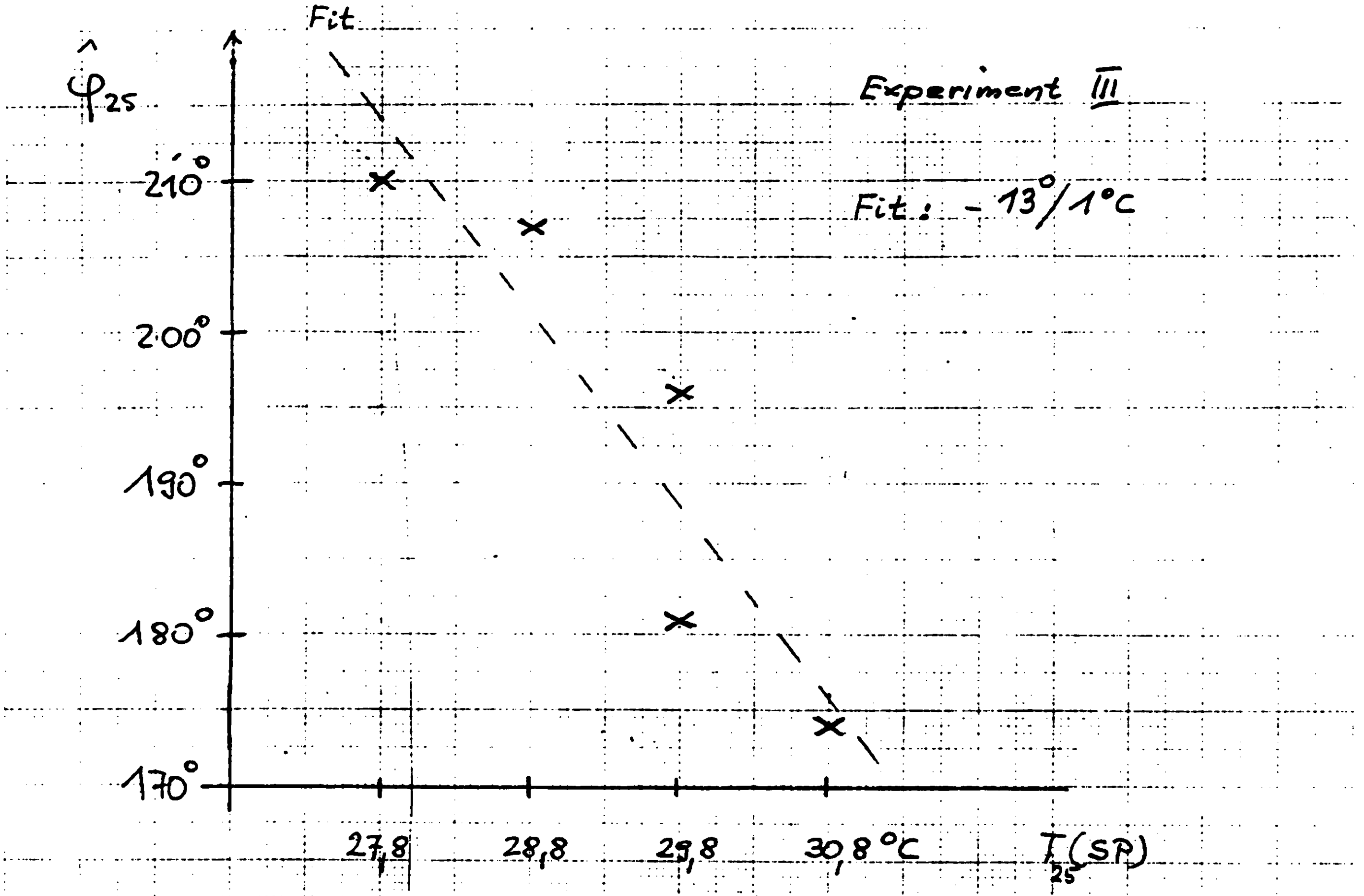


Fig. 5



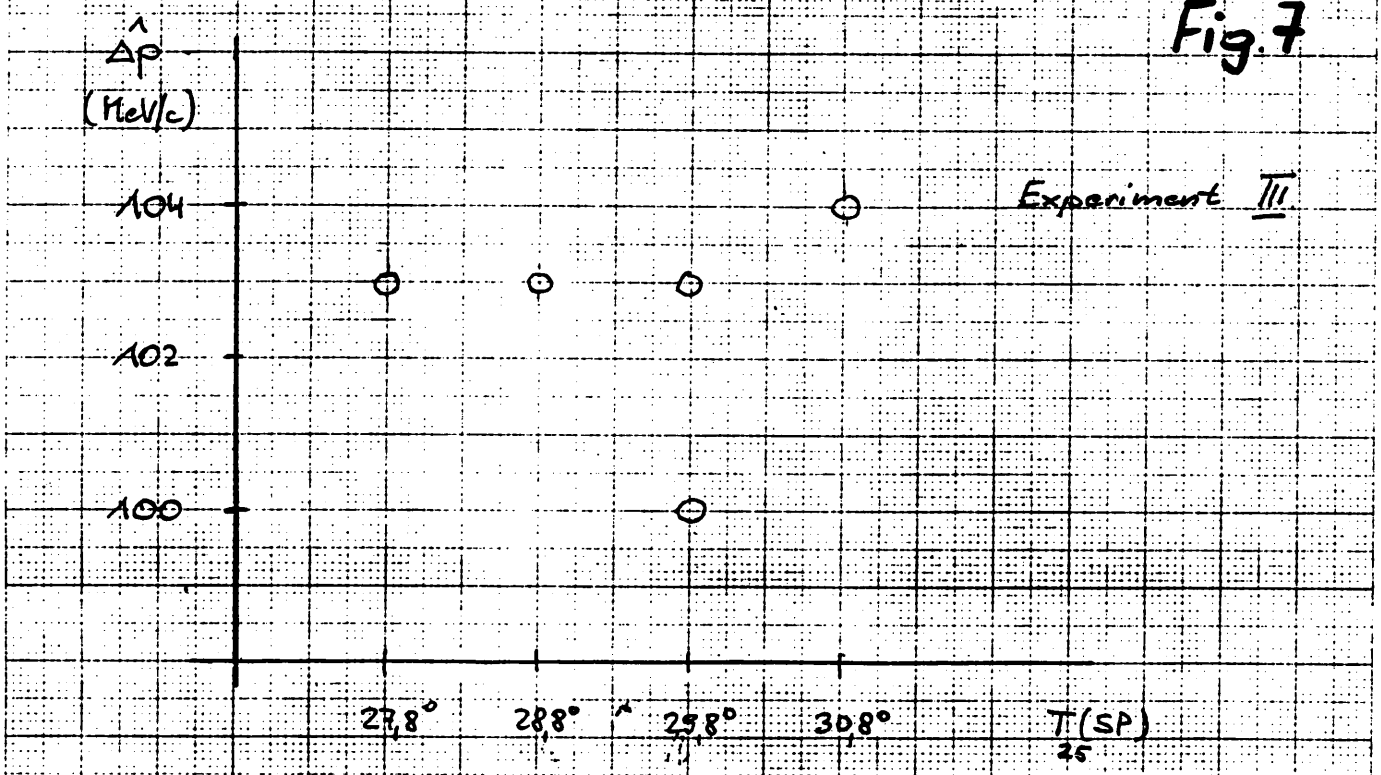
Momentum gain in AC25-26 versus φ_{25} with parameter T_{25}
Measured data: 28.8.86; Vol. III, p.5

Fig.6



Phase for maximum $\hat{\Delta p}$ versus ACS 25-26 temperature

Fig. 7



Momentum gain at optimum phase versus temperature

Fig. 8

Calibration by J.P. Perrine MDK 25 logbook 17.1.86

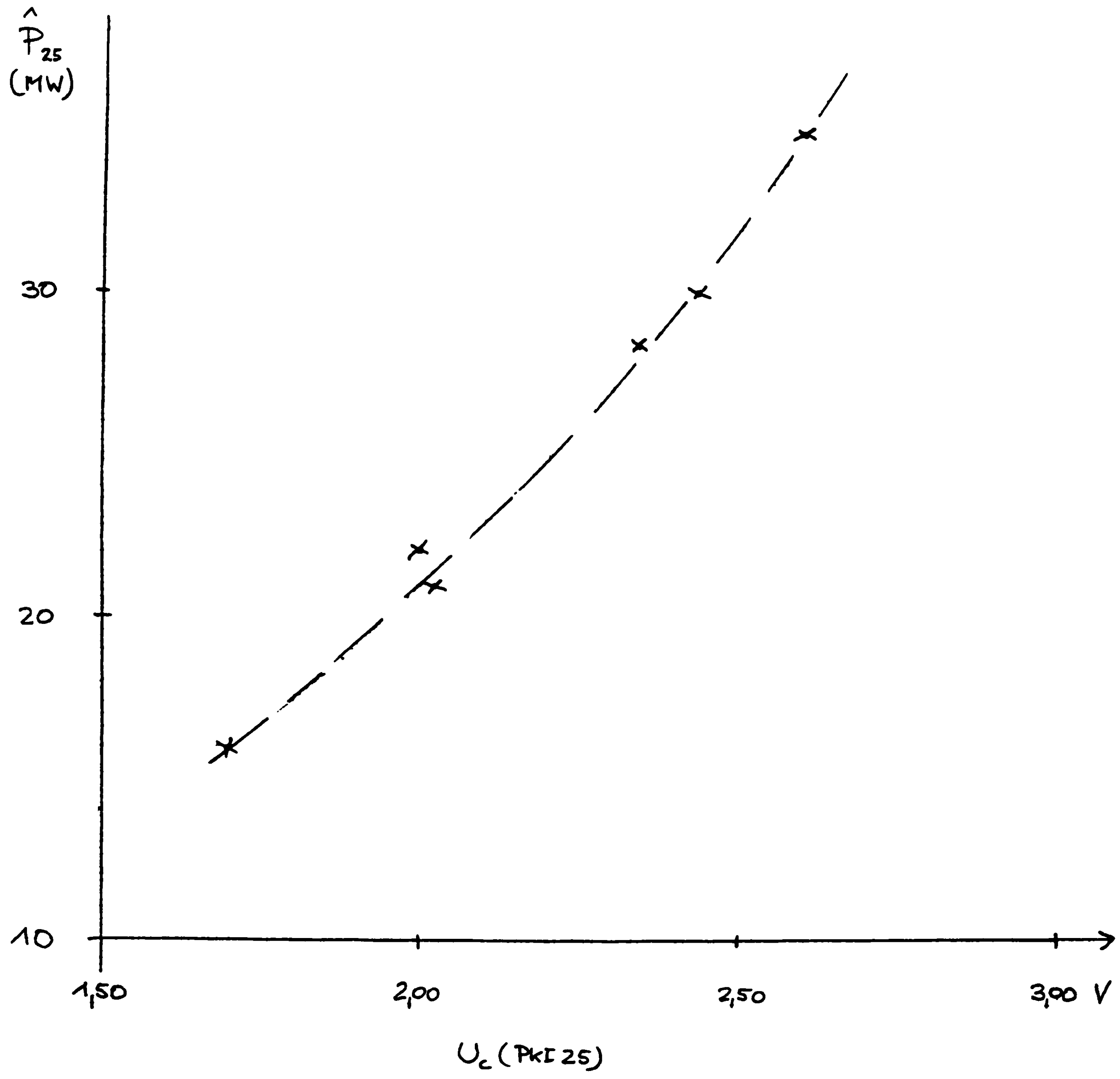


Fig. 9