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Energy Gain and Klystron Power in Linac V

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1. Theoretical Energy Gain per Accelerating Section

The theoretical energy gain for a given klystron power has been modelled by G. Bienvenu[1], with and without RF pulse compression by LIPS system.

Taking into account the measured attenuation in the LIL RF network[2], the theoretical energy gain per each section is recalled in the Appendix.

The aim of the study was to compare the corresponding theoretical figures in the 4 sections of the LIL-V powered by the klystron 13.

2. Variation of beam energy versus LIPS timing of MDK 13 on 22. 3. 1988

In order to compare the theoretical energy gain of the LIPS pulse compression scheme[1]) with beam measurements, a machine development has been carried out on 22. 3. 1988 with linac V. The beam energy was measured by the spectrometer line VL.MSH 15, see fig. 1. The maximum beam energy E = 236.2 MeV was obtained, when the phase of the LIPS-cavities was inversed at T_{IN} = 0.85 µs before the beam passes through the accelerating structure. The beam passage was observed by the intensity monitor VL.ECM 01, the RF-power in the accelerating sections was monitored by PSI 13.1, which is 4.5 m downstream of the ECM-monitor (photo 1). The beam energy for the different timings of phase inversion is shown in fig. 2. The measurements in fig. 2 agree rather well with fig. 3.1 of ref. 1.

The RF-power of klystron 13 was taken from the logs of the modulator. For PKI = 0.76 V, the power is P_{13} = 23 MW.

According to the Appendix, the theoretical energy gain E_t of the LIPS-scheme amounts per section (L = 4.5 m) to:

$$E_t = 11.24 \sqrt{P_{13}} = 53.9 \text{ MeV}$$

The beam energy at the output of the buncher was E_b = 26 ± 3 MeV (PKI 03 = 2.1 V and LBNV = 0.74 V). Therefore, the energy gain E_m measured from the spectrometer reading E_S = 236 MeV (fig. 2) is per section:

$$E_m = (E_s - E_b)/4 = 52.5 \pm 1.5 \text{ MeV}$$

In fact, the measurements on 22. 3. 1988 confirm the theoretical energy gain for an optimised LIPS-timing[1].

4. Energy gain versus klystron power of MDK 13 on 18. 10. 1988

With an optimised LIPS-timing, different power levels at the output of klystron 13 were produced by varying the RF-input of the klystron. The RF-power at the klystron output was measured with a peak-power meter HP 2900 D, Ser. N° 0244 (± 0.35 dB accuracy). The beam energy was measured by the spectrometer current BSP 15 and the beam intensity by monitor WCM 12. The measurements listed in table 1 and table 2 are represented in fig. 3.

The relation between the beam energy E_8 of linac V and the RF-power P_{13} of MDK 13 is expressed by:

$$E_8 = E_b + b \sqrt{P_{13}/MW},$$

with b as given in the Appendix.

$$b = 4 \times 11.24 = 45.0 \text{ MeV}$$

A linear fit of E_8 versus $\sqrt{P_{13} / MW}$ of the measurements provides a slope of:

$$b = 45.8 \pm 2 \text{ MeV for table 1}$$

$$b = 42.8 \pm 2 \text{ MeV for table 2}$$

The beam energy E_b at the output of the buncher is different for the measurements with the booster klystron LAL (table 1) and the booster klystron Thomson (table 2), which did not deliver the same RF-power at the input of the klystron MDK 03 of the buncher. The linear fit of the measurements provides a buncher energy

$$E_b = 26 \pm 3 \text{ MeV for booster LAL}$$

$$E_b = 32 \pm 6 \text{ MeV for booster TH}$$

The buncher energy cannot be determined from the linear fit with better accuracy since the relative errors of the spectrometer or peak power meter are magnified by a factor 10, if the beam energy is varied by only 10%.

Table 1: Energy gain E_s versus klystron power P_{13} of MDK 13
(Booster klystron LAL 11 kW)

PPI [MW]	PKI [MW]	RF IN [W]	P_{13} [MW]	Gain [dB]	BSP 15 [A]	E_s [MeV]
16.2	21.8	181	20.3	50.5	284	232
12.7	19.8	142	18.4	51.1	272	222
10.0	17.9	112	16.6	51.7	259	212
8.0	16.3	90	15.2	52.3	246	204

$\left.\begin{aligned} \text{RF IN} &= (1.12 \pm 0.13)\ 10^4 \cdot \text{PPI} \\ P_{13} &= (0.93 \pm 0.12)\ 10^6 \cdot \text{PKI} \end{aligned}\right]$ calibration factors of couplers and probe

$E_s = E_p + 3$ MeV $= 232$ MeV $\cdot$ BSP 15/284 A,

E_s is the maximum energy of the beam (no beam loading).

E_p is the energy of the density peak of the spectrum.

The beam loading of the accelerating structures reduces the accelerating voltage by about 3 MeV for a beam charge of Q = 2.9 nC.

Table 2: Energy gain E_s versus klystron power P_{13} of MDK 13
(Booster klystron Thomson 23 kW)

PPI [MW]	PKI [MW]	RF IN [W]	P_{13} [MW]	Gain [dB]	BSP 15 [A]	E_s [MeV]
16.2	21.7	181	20.2	50.5[1)]	275	225
20.2	23.1	226	21.5	49.8[1)]	283	231
25.3	24.0	283	22.3	49.0[1)]	287	234
27.9	24.2	312	22.5	48.6[1)]	289	235
16.2	26.4	181	24.6	51.3[2)]	301	245
20.2	27.5	226	25.6	50.5[2)]	306	249
25.3	27.9	283	26.0	49.6[2)]	307	250

[1)] U_k = 256 kV, I_k = 254 A [2)] U_k = 271 kV, I_k = 276 A

5. Beam loading in linac V on 18. 10. 1988

The beam loading of linac V was measured by increasing the beam intensity from 0.13 A to 2.4 A. The measurement of the beam profile is not accurate, since the gain of the semgrid was set too low. Nevertheless, it can be seen from from fig. 4 and 5, how the energy spectrum widens with increasing beam charge Q. For an accurate measurement of the beam loading factor in linac V, the beam intensity must be measured for every RF-structure by means of the monitors ECM01, WCM11, WCM12, UMA13, UMA14 and UMA15 [3-4]. It is most important to measure the beam emittance and to deduce its effect frm the beam profile measurement[5].

Acknowledgements

We would like to thank Kurt Hűbner for his numerous suggestions and for his comments on the measurements.

References

[1] G. Bienvenu, Gain d'énergie dans les sections LIL-W en mode LIPS, LAL PI 86-117/T

[2] D. Blechschmidt and D.J. Warner, Parameters of the LEP Injector Linacs, CERN/PS/88-07 (LPI), p. 25, 26

[3] B. Canard, K. Hűbner et al., Measurement of LIL convesion efficiency, PS/LP Note 89-02

[4] J.H.B. Madsen, D. Pearce, A. Riche, Effects of the beam size at the target for the e+ production, PS-LP Note 89-07.

[5] E. Cherix, A. Riche, L. Rinolfi, First measurements of e^- linac emittances after changing of gun V, Note PS-LP 89-09

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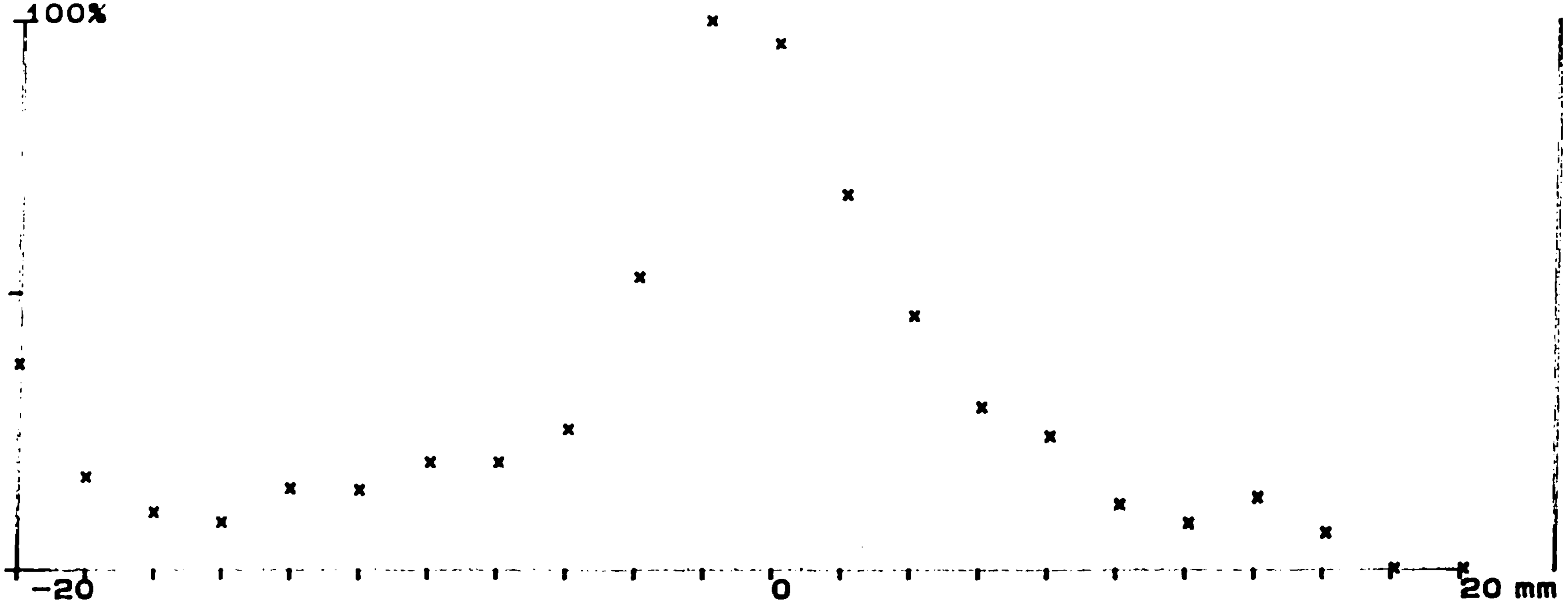
BEAM PROFILE MEASUREMENT - VL.MSH15



BSP 15 = 292 Amp

Central Energy 235.45 MeV

Digital Value at 100% 280 (sat. 2047)

Intensity (UMA meas.) -12.123 1E8 part.

Number of measurements 14

Residual is 37 % of maximum

Scraper VL.SLV12 (Aperture) : 48.87 (50) mm

(Position) : 0 (0) mm

T_1 : 36 μsec

T_{IN} : 0.8 μsec

conclusion E optimum (236,2 MeV) pour

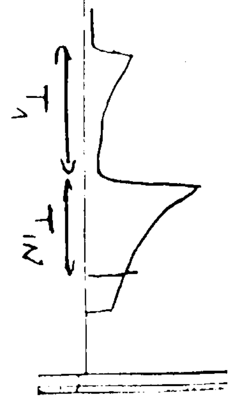


Fig. 1 Beam Energy of Linac V

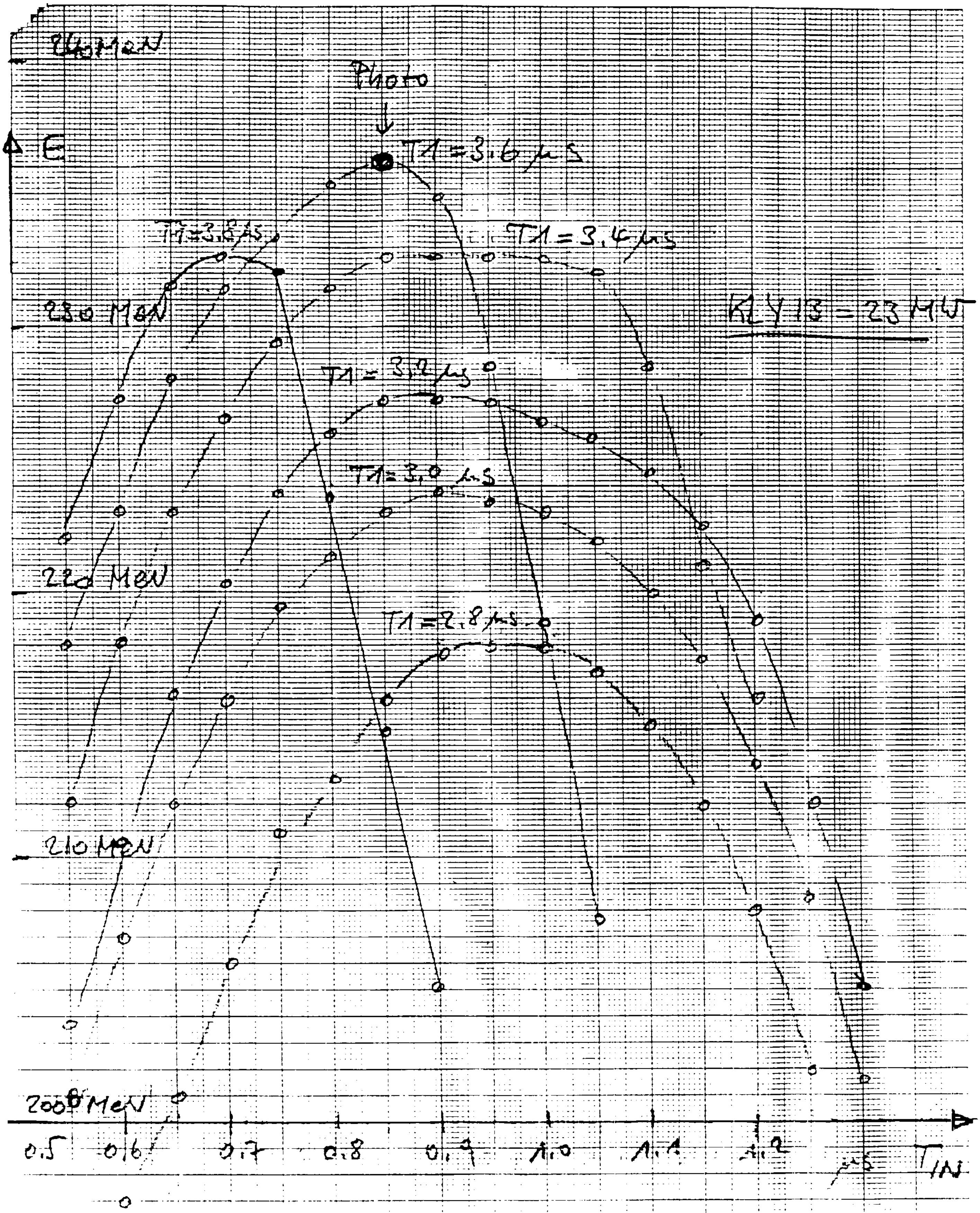
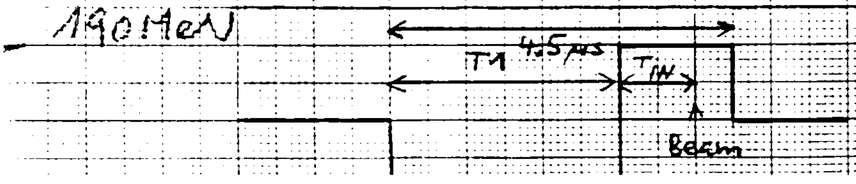


Fig. 2

Energy Gain vs. LIPS Timing of KLY 13



23.3.88

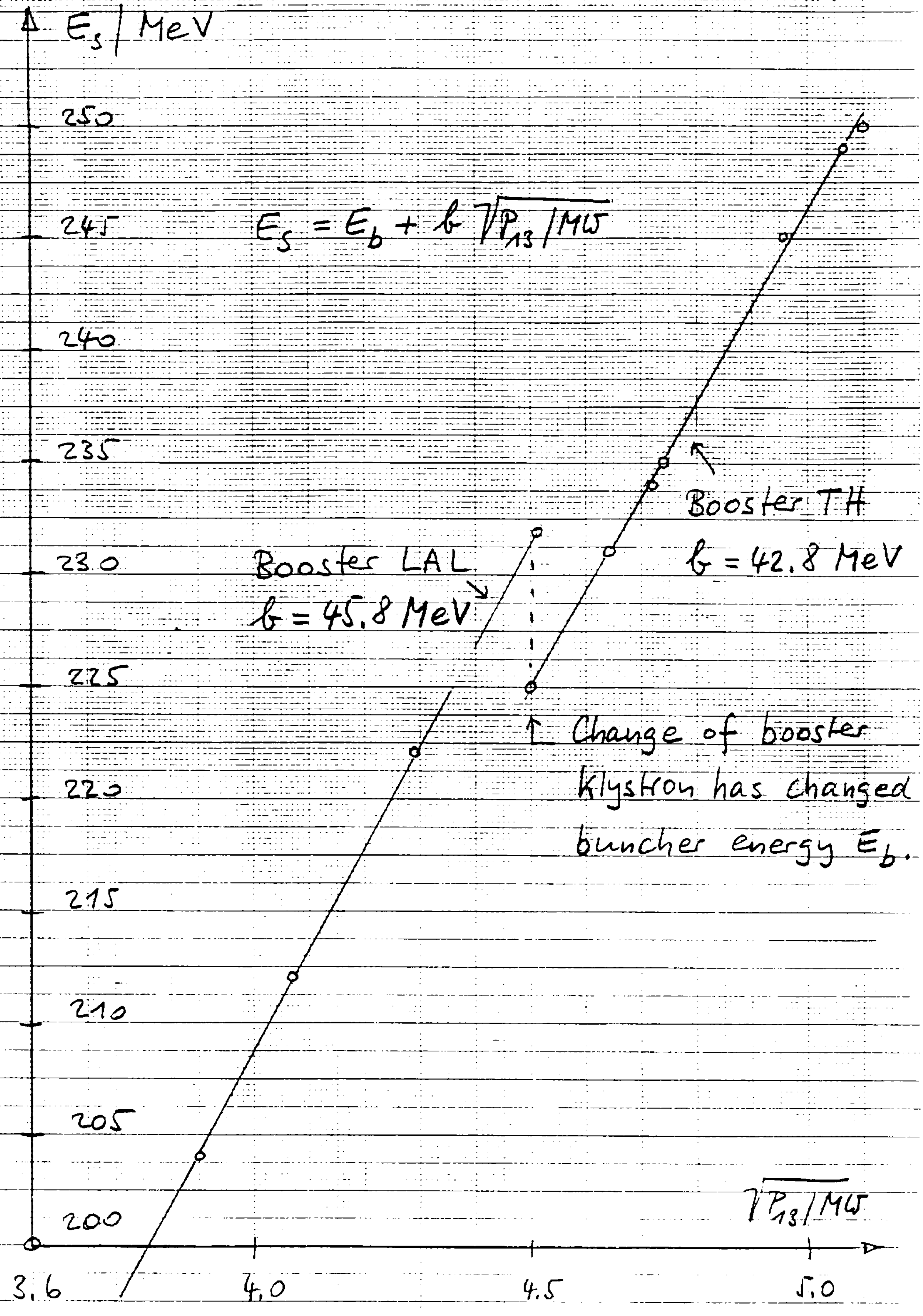


Fig. 3 Beam energy of LIL-V versus klystron power P_{13} and buncher energy E_b.

26.1.89

Fig. 4 Beam profile MSH 15 for Q = 2.73 nC

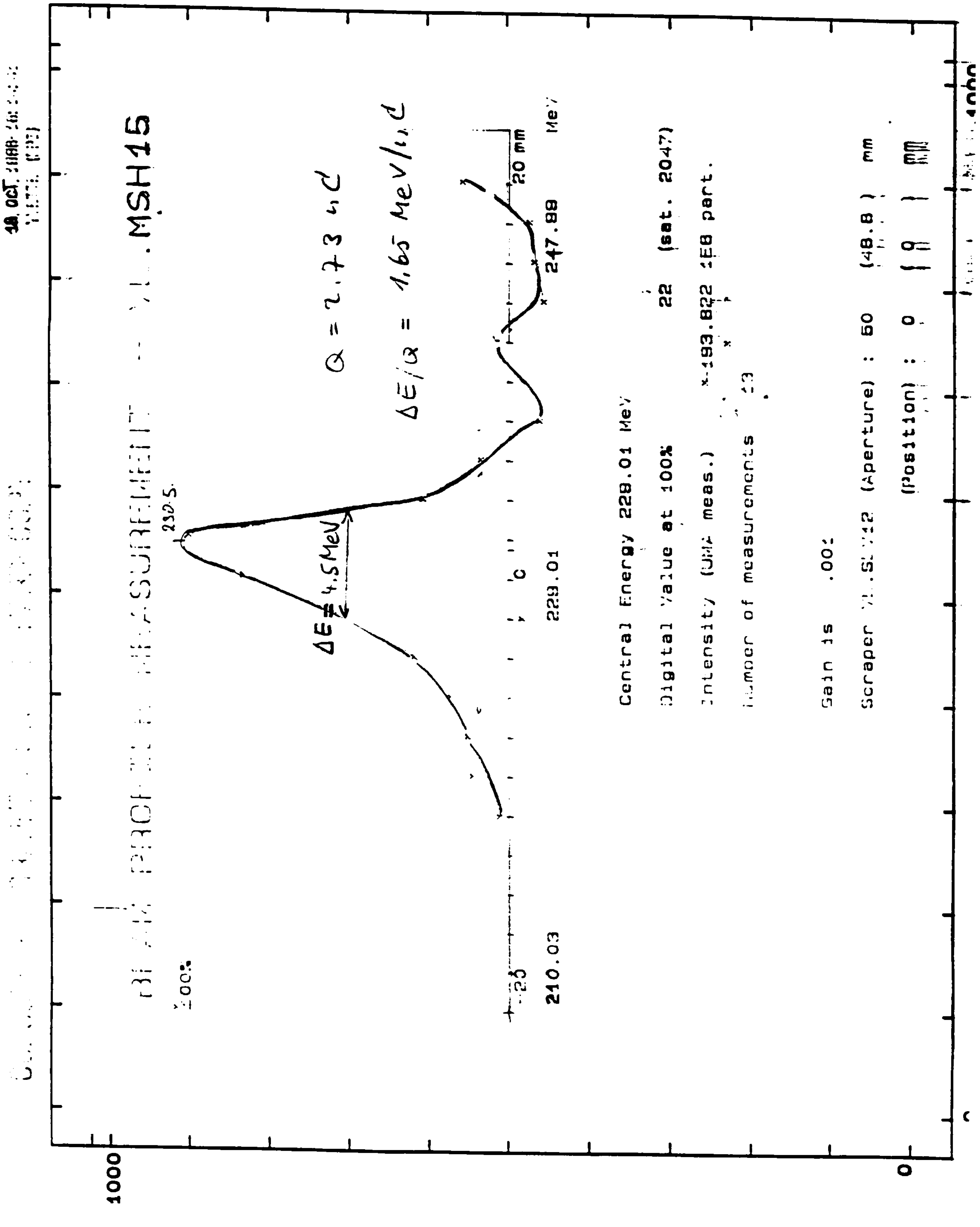
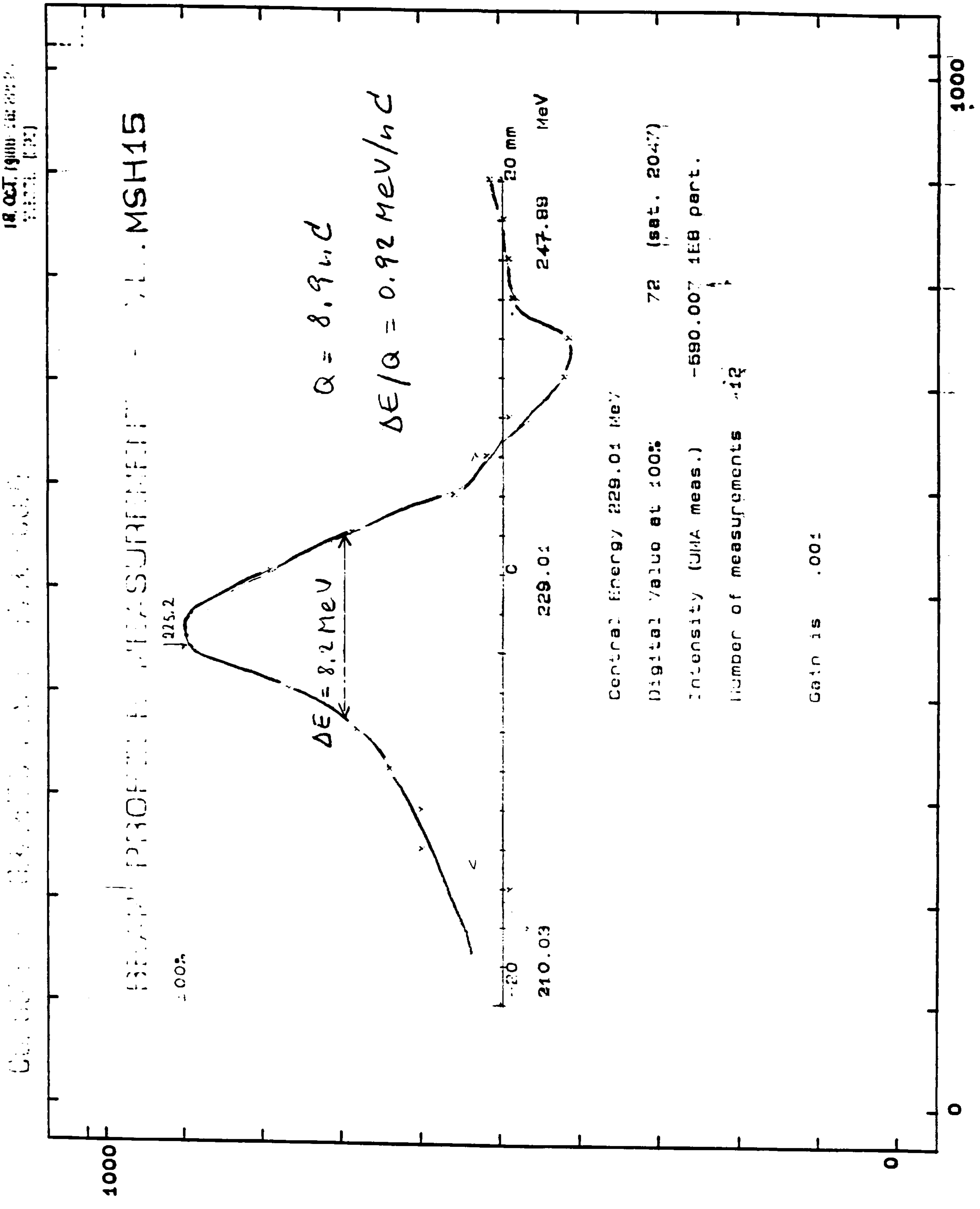


Fig. 5 Beam profile MSH 15 for Q = 8.9nC



A P P E N D I X

Energy gain per accelerating section

The energy, E_n gained in n accelerating sections fed by one klystron, k, is given by

$$E_n = \sum_{i=1}^{n} E_i = \sum_{i=1}^{n} \sqrt{R'_s\ L\ P_i}$$

where E_i is the energy gain of the individual section and R'_s the mean shunt impedance per meter of accelerating section.

L = 4.5 m is the useful length of the section

P_i= the effective power at the entry of the section

Following the theoretical calculations[1] of the energy gain E_i per section powered with a constant power P_i

$$\left.\begin{array}{l} P_i = 15\ \text{MW} \\ E_i = 60.5\ \text{MeV} \end{array}\right] \rightarrow R'_s = 54.2\ \text{M}\Omega/\text{m}$$

The RF power at the entry of the section is derived from the power delivered by the klystron, P_k, as follows:

$$P_i = g\ 10^{-\alpha i/10}\ P_k$$

where

α_i is the attenuation as measured[2] in dB of the RF network

α_{11} = 6.57	α_{12} = 6.47	α_{13} = 6.32	α_{13} = 6.30
α_{25} = 3.35	α_{26} = 3.38		
α_{27} = 6.28	α_{28} = 6.33	α_{29} = 6.45	α_{30} = 6.53
α_{31} = 6.33	α_{32} = 6.40	α_{33} = 6.48	α_{34} = 6.58
α_{35} = 3.35	α_{36} = 3.35		

and g is the multiplication factor provided by the system LIPS.

Then

$$E_n = \sum_{i=1}^{n} \sqrt{R_s\ L\ g\ 10^{-\alpha i/10}\ P_k} \quad \text{and} \quad E_i = \frac{E_n}{n}$$

The power gain, g, is obtained by compression from a rectangular RF pulse of 4.5 µsec duration delivered by the klystron into an exponentially falling pulse with an e-folding time of 1.15 µsec. With an optimum setting of the timing of the phase inversion at the LIPS cavity, the peak amplitude of the LIPS output power is about three times higher than the klystron power and the effective power gain at the beam passage is given by[1]:

$$\left.\begin{array}{l} E = 64.4 \text{ MeV} \\ P_k = 7.5 \text{ MW} \\ a = 0 \text{ dB} \end{array}\right] \quad g = 2.27$$

Therefore the energy gain per group of sections powered by a single electron is given by

without LIPS:

$$\left.\begin{array}{l} n = 2 \\ g = 1 \end{array}\right] \quad E_i \text{ (MeV)} = 7.81 \sum_{i=1}^{2} 10^{-\frac{\alpha i}{20}} \sqrt{P_k \text{ (MW)}}$$

with LIPS

$$\left.\begin{array}{l} n = 4 \\ g = 2.266 \end{array}\right] \quad E_i \text{ (MeV)} = 5.88 \sum_{i=1}^{4} 10^{-\frac{\alpha i}{20}} \sqrt{P_k \text{ (MW)}}$$

Klystron	Sections	$\sum_{i=1}^{4} 10^{-\frac{\alpha i}{20}}$	E_i (per section) MeV/(MeV)$^{1/2}$
13	11, 12, 13, 14	1.911	11.24
25	25, 26	1.358	10.60
27	27, 28, 29, 30	1.915	11.26
31	31, 32, 33, 34	1.904	11.20
35	35, 36	1.360	10.62

The theoretical setting per klystron is then deduced for various positron beam energy at the exit of LIL-W.

Total energy (e^+) (MeV)		Energy/Section W MeV	P_{25} (MW)	P_{27} (MW)	P_{32} (MW)	P_{35} (MW)
516 + 4	at exit from converter	43.0	16.5	14.6	14.7	16.4
566 +		47.2	19.8	17.6	17.8	19.8
616 + 4		51.3	23.4	20.8	21.0	23.4