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A DEVICE FOR MEASUREMENTS OF THE FLUX DENSITY DISTRIBUTION OF PROTONS IN FAST AND SLOW EJECTED PROTON BEAMS

by

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1. INTRODUCTION

A knowledge of the size and position of a proton beam along its path is needed essentially during setting up periods, and should be measured continuously e.g. at the entrance of a beam transport system or in front of a target during the whole experiment.

In spite of the limited accuracy and short life due to radiation damage, scintillating screens viewed by television cameras are often preferred because of their direct visual display. For a position control of the beam centre pick-up electrodes of the electrostatic type are valuable non-intersecting devices with good spatial resolution.

Devices to monitor the flux density distribution of proton beams are still under development and up to now only intersecting methods yield the necessary resolution of less than one millimetre with a few percent error. If only single checks are needed an activation method may be used, inserting crossed stacks of thin metal strips and counting the activity induced.

For continuous monitoring electrons or ions produced by the ionisation of low pressure gas molecules may be collected and yield information on the beam size 1). Another system developed by Budal 2) uses the charge transport from targets as a means to scan a high energy proton beam. We propose to build a device based on this charge transport effect, inserting a grid of wires or strips and a special memory and read-out system. With this it should be possible to register the position and density distribution of each burst of an ejected proton beam. For the target efficiency checks in the neutrino beam line this monitor would be a very useful instrument.

2. DESCRIPTION OF BASIC IDEAS OF THE SYSTEM

A target hit by high energy protons emits charge due to three different emission mechanisms :

1. Escaped knock-on electrons;
2. Shower particles from nuclear interactions;
3. Secondary emission electrons from the surface.

The main contribution comes from knock-on electrons and is a volume effect. This is also true for shower particles produced in nuclear interactions.

The measurements of Budal show that the charge removal from targets of small lateral dimensions is proportional to the number of interactions in the target. No saturation effects were observed at the highest PS-intensities and the reproducibility was good. The efficiency of the charge emission was found to be of the order of 0.04 electrons per penetrating proton. For monitoring the proton beam during the 1967 neutrino experiment a system using a 100 mm long AL-target of cross section 1 x 1 mm^2, which could be moved through the beam was successfully used for beam scanning. In this case the lower limit of the signal was given by the capacity of a long cable connecting the target to the charge sensitive amplifier in the control station.

We propose a system comprising a grid of thin wires or foils. To avoid the operation of charge sensitive amplifiers in the high radiation region near the beam the charge will be simply stored in cables of 1 to 2 metres length. This short memory cable will be connected to each wire or foil. After a certain "waiting" period in which most of the radioactivity will have decayed the read-out will start. Each memory cable will then be switched over one common signal cable to connect the beam area with the control-station. This results in a fast pulse at the end of the line. According to the length of the storage cable the pulse width will be different and the voltage is dependent on the cable capacity and its attenuation. The switching element will consist of a fast reed-switch together with suitable coils. These relays operate reliably for several million actuations and are not damaged by radiation. They can be properly matched to the storage and signal cables. The output of the signal cable will be a train of pulses and the pulse height proportional to the number of protons which passed the wire or foil. Taking into account the efficiency of charge emission (4 o/o) and assuming a proton beam cross section of 10 x 10 mm^2 and a homogeneous distribution of 10^{12} protons a foil of 10 μm thickness and 1 mm width would give for a cable capacity of 100 pF a signal of about 1 Volt.

The width and number of wires or foils per mm determines the resolution of the system. It is hoped to have a resolution better than 0.5 mm.

3. LABORATORY TESTS ON WIRES, CABLES AND REED-RELAYS

A) Wires. A plexiglass frame with several Al-wires of 0.5 mm diameter was prepared for measurements in the proton beam. Because of the operation in open air all wires were treated chemically to have an insulation layer of about 20 microns of AL_2O_3 around. For high isolation purposes the spacing between two adjacent wires was 20 mm.

B) Cables. Because of their mechanical similarity and ease in handling we selected the following types of cables :

50 Ω	RG	58 CU
75 Ω	RG	59 CU
125 Ω	RPG	1740

C) Reed-Relays. Three types of reed-relays were used in order to determine whether their characteristics were similar :

1. Mercury filled relays
2. Relays filled with inert gases (e.g. nitrogen)
3. Relays operating in vacuum.

Each relay was put into a coaxial mounting adapting the impedance to its corresponding cable. These mountings were surrounded by bobbins of 100 A turns. The following relay and cable features are relevant for the operation of our device.

1. The ohmic resistance of the relay with open and closed contacts.
2. The shortest time to actuate the relay through a whole cycle i.e. from the open state over to the closed state back to the open state.
3. The time jitter.
4. Storage time and losses.

1. Using a pico-ammeter and 100 Volts DC at the leads of the relay with open contacts, the leak current was measured. It was seen that the equivalent resistance of a number of relays measured varied from 10^{10} to more than $10^{13}\,\Omega$. It is this resistance which limits the storage time of a cable connected to ground by an open relay. Therefore only relays with at least $10^{13}\,\Omega$ were selected for further tests. The contact resistance was of the order of 100 mΩ depending on the load conditions.

2. The read-out time is limited by the shortest possible cycling of the relays, because the first relay has to be open again before the next one should be actuated. If one applies a current pulse (Δt_R) to the relay coil the contact closes with a certain time delay (Δt_s) due to mechanical inertia of the system. This delay becomes minimum and stable when the current pulse is sufficiently long. It was found for optimum operation, that the minimum length Δt_R of the current pulse applied to the relay coil varied between 0.6 and 3 msec. The corresponding time delay Δt_s, varied between 0.4 and 2 msec, but was not constant for relays of similar types. This gives us cycling sequences (C) up to 5 msec. The fast pulse from a stored charge on the cable, however, appears with the first closing of the relay contact (see fig. 1).

3. The jitter of the fast signal will be several microseconds. A somewhat bigger jitter up to 50 µsec was observed with the mercury filled relays. This jitter also depends strongly on the repetition rate. (We normalized to rates of about 1 - 2 pulses per second). The following table shows some typical results.

TYPE	Δt_R [ms]	Δt_S [ms]	a.C [ms]	jitter [μs]
50Ω vac	3.0	2.0	5.0	6.0
50Ω N_2	0.6	0.6	1.2	3.0
50Ω Hg	1.2	0.4	1.6	4.0
75Ω Hg	2.5	1.7	4.2	10.0
125Ω Hg	2.5	1.7	4.2	50.0

4. Equal lengths of 1 m cable were mounted onto coaxial relay carriers giving well matched impedance lines for each type of cable. With the circuit shown in Fig. 2 the cable was charged to 40 Volts with relay 1 and then opened. After a variable time delay Δt the relay 2 was actuated and the outcoming pulse height observed as a function of time. After 3 minutes the charge was still fully conserved and even after several hours on some cables we observed the same pulse height as after the charging up. This shows the very good isolation in the system and specially across the switch (relay).

   The AL-wires were then connected to the charge line and no decrease of the stored voltage could be observed over the same time intervals. The question arose if in radioactive zones a similar storage time could be achieved? The attenuation of the signal was measured by using different lengths of cables on the discharge line (see fig. 2). Taking 30 m of cable for the signal transport we found losses between 10 - 20 % according to the different cable types. Better results could be obtained by using low loss cables.

4. MEASUREMENTS IN THE EJECTED PROTON BEAM

To investigate the working performance in a region of high radiation the apparatus was placed into the K 8 beam. 25 % of the total PS intensity were ejected in the fast-slow mode in a burst of 1 - 2 msec length. The target of 1 x 1 x 10 mm^3 Be was situated in a steel-blockhouse.

The proton beam left the vacuum pipe 4 m upstream and was travelling through air towards the target. The proton momentum was 19.2 GeV/c and the repetition rate 2.3 sec. The relays were not shielded against radiation and were 50 cm away from the beam line as were also the AL-wieres. Thus the charge on the wires was only influenced by secondary radiation.

4.1 Storage time

The storage time of 5 prototype detectors with 1 m of memory cable was measured in a manner identical to the laboratory tests. The cables were charged to a fixed voltage of 9.5 Volts. With a variable time delay with respect to the passage of the beam the relay was actuated and then the remaining charged controlled. Fig. 3 shows the experimental arrangement and the timing sequence.

As already expected, there was an observable leakage of the electric charge in the storage line. This was especially pronounced immediately after the passage of the beam which lasted only a few milliseconds. With the decreasing secondary radiation field in the target area the voltage drop becomes much smaller. Fig. 4 shows this effect as a function of the time delay for 2 prototypes of different impedance.

A variation of the radiation background by about a factor 4 was achieved by putting a 2 mm thick iron plate into the beam. The plate was put at the end of the vacuum pipe as an additional target for secondary particle production. Fig. 5 shows the obtained results for two different radiation levels.

4.2 Beam Scanning

The possibility of scanning the beam density distribution was tested in a fast ejected proton beam with 6 bunches of 19.2 GeV/c.

The plexiglass frame was put into the beam line and a precision motor with remote control allowed displacement facilities in the horizontal and vertical plane. The target was about 2 metres downstream. For independent measurements always one single wire was used for beam scanning. It was moved across the beam path step by step during several bursts. The relays were all actuated 100 msec after the passage of the beam. The following curves (Figs. 6,7) give an idea of the pulse output for the various arrangements. Fig. 6 shows the beam profile of two various beam shapes.

Fig. 7 shows different beam scans with 3 basic impedance lines. The beam shape was not constant during the measurements therefore no conclusions about the profile should be drawn by comparing the three curves.

Occasionally with 20 bunches ejected and a circular beam of 1 cm diameter signals of more than 10 Volts have been observed on the 125 Ω line. This of course was measured in the beam centre. There was also good agreement between pulse height and different bunch numbers (i.e. intensity of proton beam).

5. ELECTRONIC READ-OUT AND DISPLAY SYSTEM

By the passage of the beam n-cables of impedance Z_o (50, 75 or 125 Ω) will be charged according to the beam intensity distribution. The purpose of the read-out part is to measure this induced charge on each cable and to give the result as fast as possible. Fig. 8 gives the general block-diagram of the system and Fig. 9 shows the timing.

The charge of each cable is measured by discharging one after the other across a switch r_n of n reed relays R_n. These relays are triggered in a special timing sequence delivered by TIMING 1. The basic time θ will be around 5 msec.

The tension across the termination resistance Z_o will be measured by an ADC (type EG 8 G) modified in such a way to obtain coded BCD information in 2 decades : units and tens. This information will be successively transferred to n-registers of 8 bits each by timing 2. Results from these registers are taken by groups of 4, transferred to the printer and controlled by timing 3. At the same time timing 3 supplies the corresponding address of each wire or foil to the printer.

After the completed reading of n-cables, the system will be calibrated by application of a DC-voltage on n-cables. The tension will be supplied over the switch r_c actuated by relay R_C with all reed switches closed. The successive reading of each cable will be done in the same way as mentioned above : read-out - digital conversion memorisation and finally print out.

A useful printer would be Hewlett-Packard model 5050 A which allows printing of 20 lines per second, each line having a capacity of 18 columns.

If one wants a precision of 1 % each result needs two digits (from 0 to 99); the address also needs 2 digits (for $n < 100$). In this way it is possible to print 4 results per line using 16 columns as for example :

1 2 3 4	5 6 7 8	9 10 11 12	13 14 15 16	17 18
cable 1	cable 2	cable 3	cable 4	
01 12	02 75	03 17	04 25	
address charge	address charge	address charge	address charge	

Supposing a double grid of 20 horizontal and 20 vertical wires or foils the 40 results could be printed on 10 lines taking a print time of 500 msec. For a PS-repetition rate of 1 sec one could record the results of 40 wires including a waiting period after the passage of the beam up to 200 msec, a read-out period of less than 300 msec and finally a print time of 500 msec.

6. COST AND TIME ESTIMATES

The main expenses will be given from the three following items :

1) Analogue to digital converter

2) Printer

3) Logic

The converter will be from EGG type AD 128 with a basic price of $ 750 - say S.Fr. 3000.-. With power supply and level converters (NIM-TTL) the total will amount to about 4000 S.Fr. As printer we have foreseen Hewlett Packard type 5050 A which will amount to 120.00 S.Fr. for 16 columns including control amplifiers.

The logic will consist of mainly NPA logical circuits and will amount to 13000 S.Fr. or totalizing :

ADC	4000
Printer	12000
Logic	13000
	29000

This sum does not comprise development and final construction of gratings, cable connections and the coaxial relay distributer. It is hoped to realize a system for the electronic read-out of 20 wires in 2 months time if there is no delay in the delivery of material and in the cabling.

At the beginning of the year 1969, there will be the first tests of a complete system of 20 wires which can be arranged in either horizontal or vertical position. After this next step a decision on further improvements and constructional details will be taken.

7. CONCLUSIONS

From the results of the tests described it is concluded that such a system could work satisfactorily. Nevertheless a more detailed study is required for better understanding and improvement of the system. The following points show some of the problems which should be studied during further test runs.

1. On the ground of dynamical and electrical tests in the laboratory the best type of relay has to be found by careful selections.
2. Development of a final read-out and display system to obtain automatic beam profile displacement.
3. Measurements in an ejected proton beam with variation of the radiation background up to the highest possible level, i.e. directly in front of a target (survey of radiation levels).
4. Influence of surrounding gas on storage time.
5. Possibility of installing an electric sweeping field around the wires or strips.
6. Oxide insulated wires or pure aluminium. 4
7. Determination of the factor responsible for charge decay (relays or cables etc.).
8. Linearity and stability tests.
9. Maximum resolution.

8. ACKNOWLEDGEMENTS

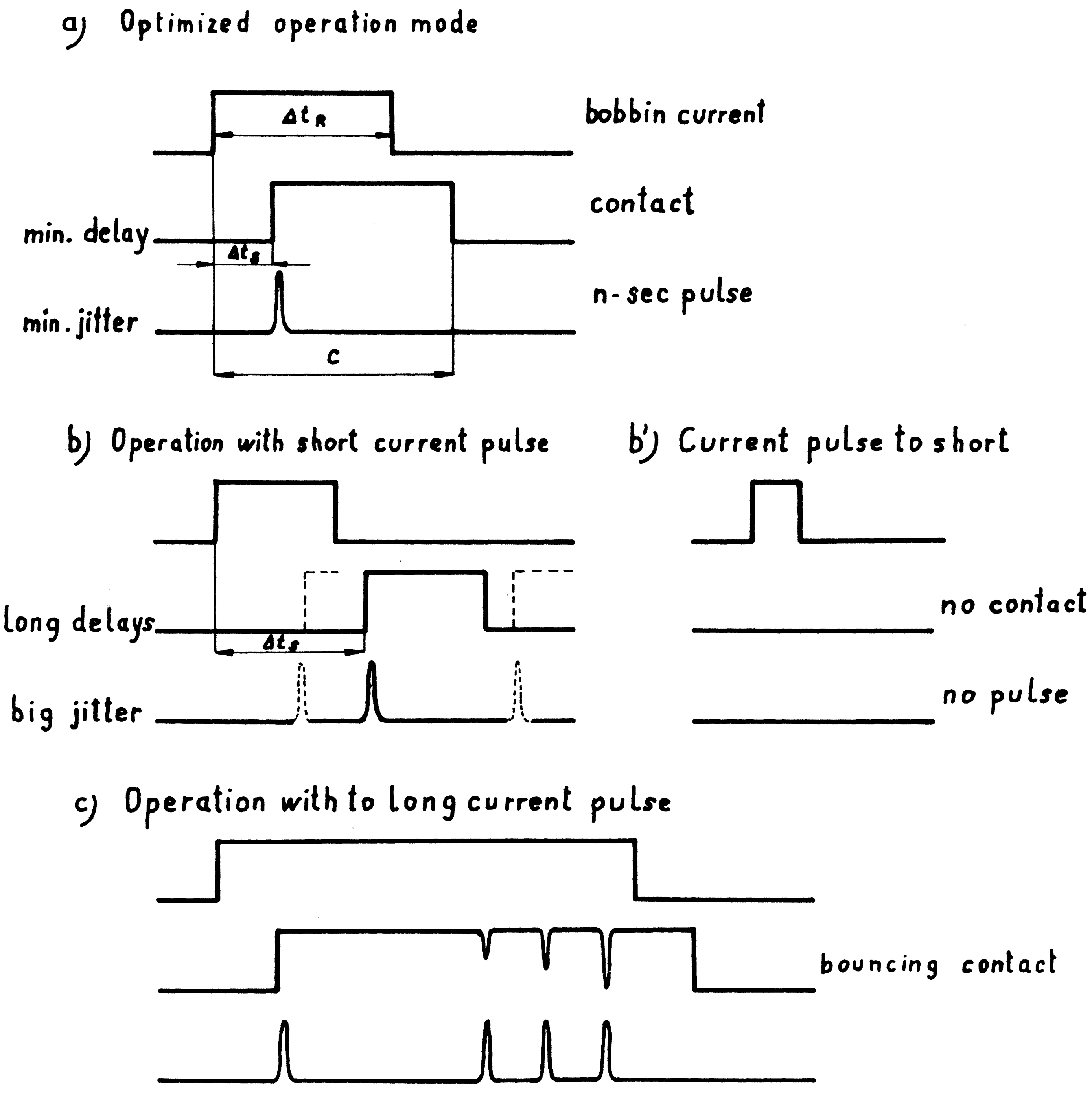
We wish to thank Mr. J. Gardies who constructed all the mechanicals parts of the apparatus and made the drawings of this paper. Finally we are very grateful to Dr. C.A. Ramm for his encouragement.

9. REFERENCES

1. C.D. Johnson and L. Thorndahl - MPS/Int. Co 68-8
2. K. Budal - CERN 67-17

Distribution : (open)
Scientific staff of N.P.A.

PS/6883


a) Optimized operation mode

b) Operation with short current pulse

b') Current pulse to short

c) Operation with to long current pulse

Fig. 1

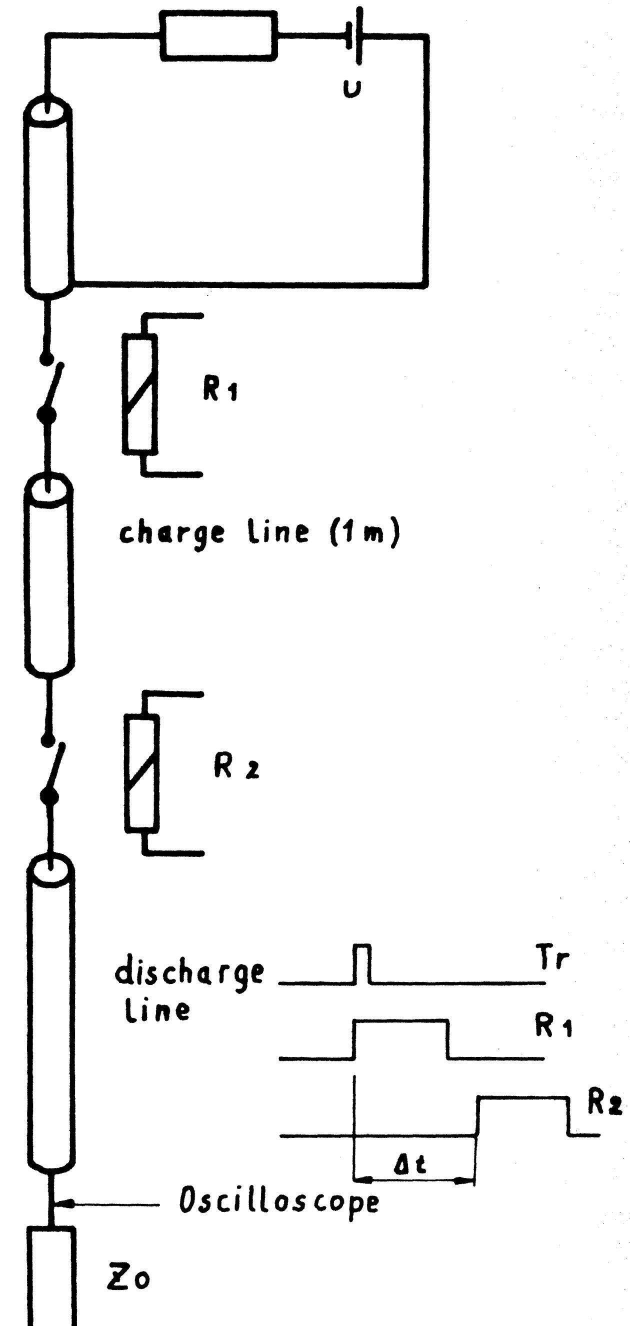


Fig. 2

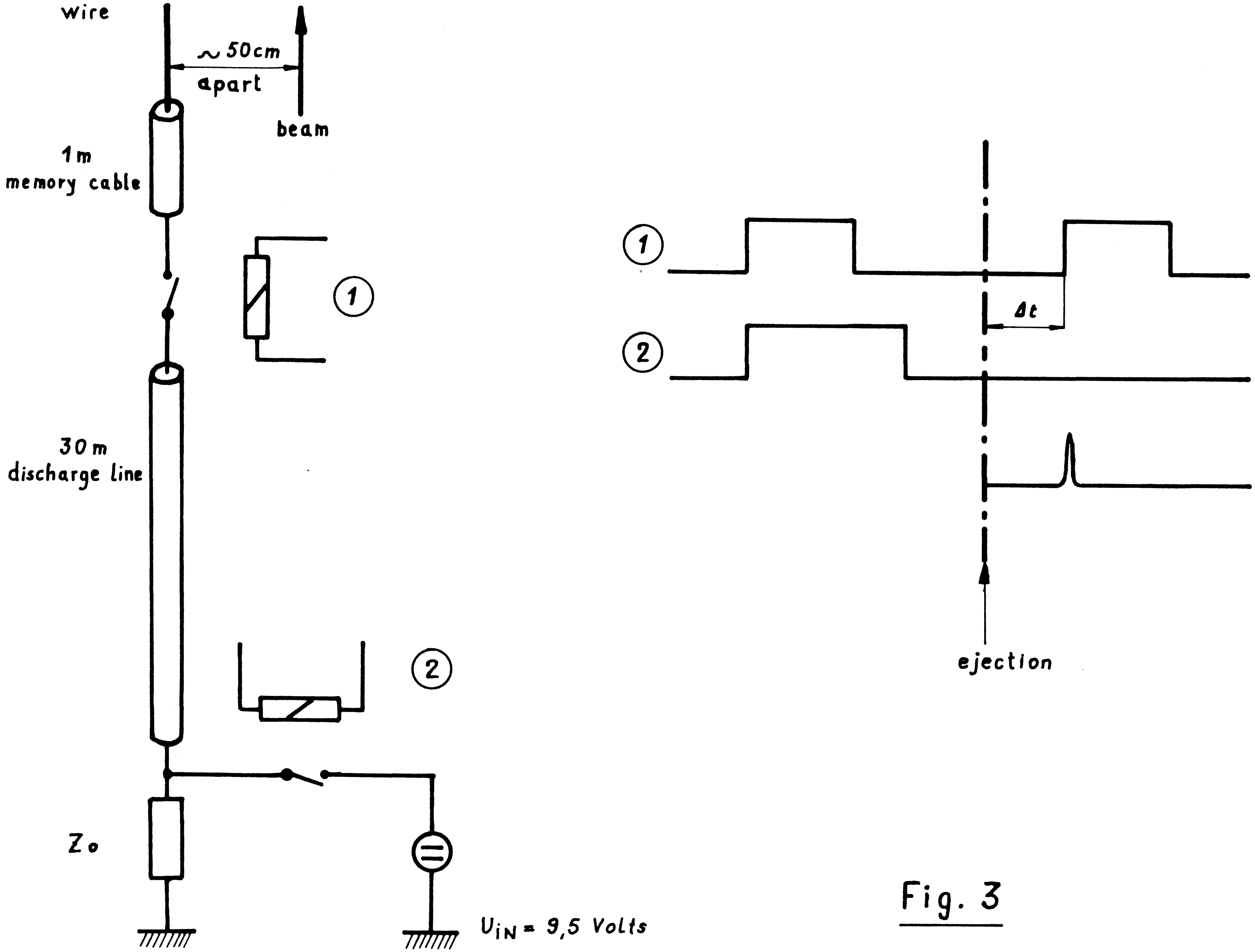
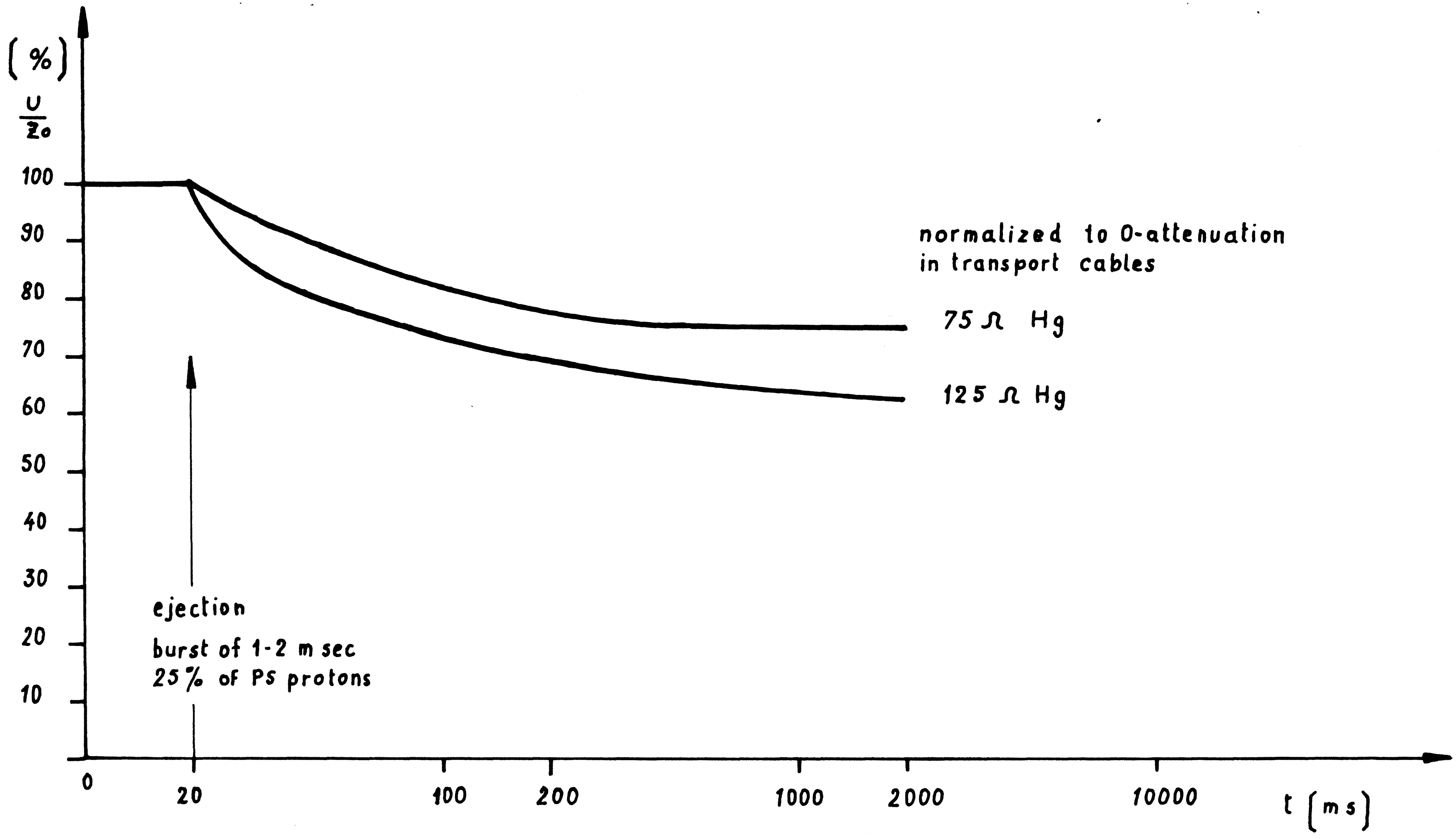
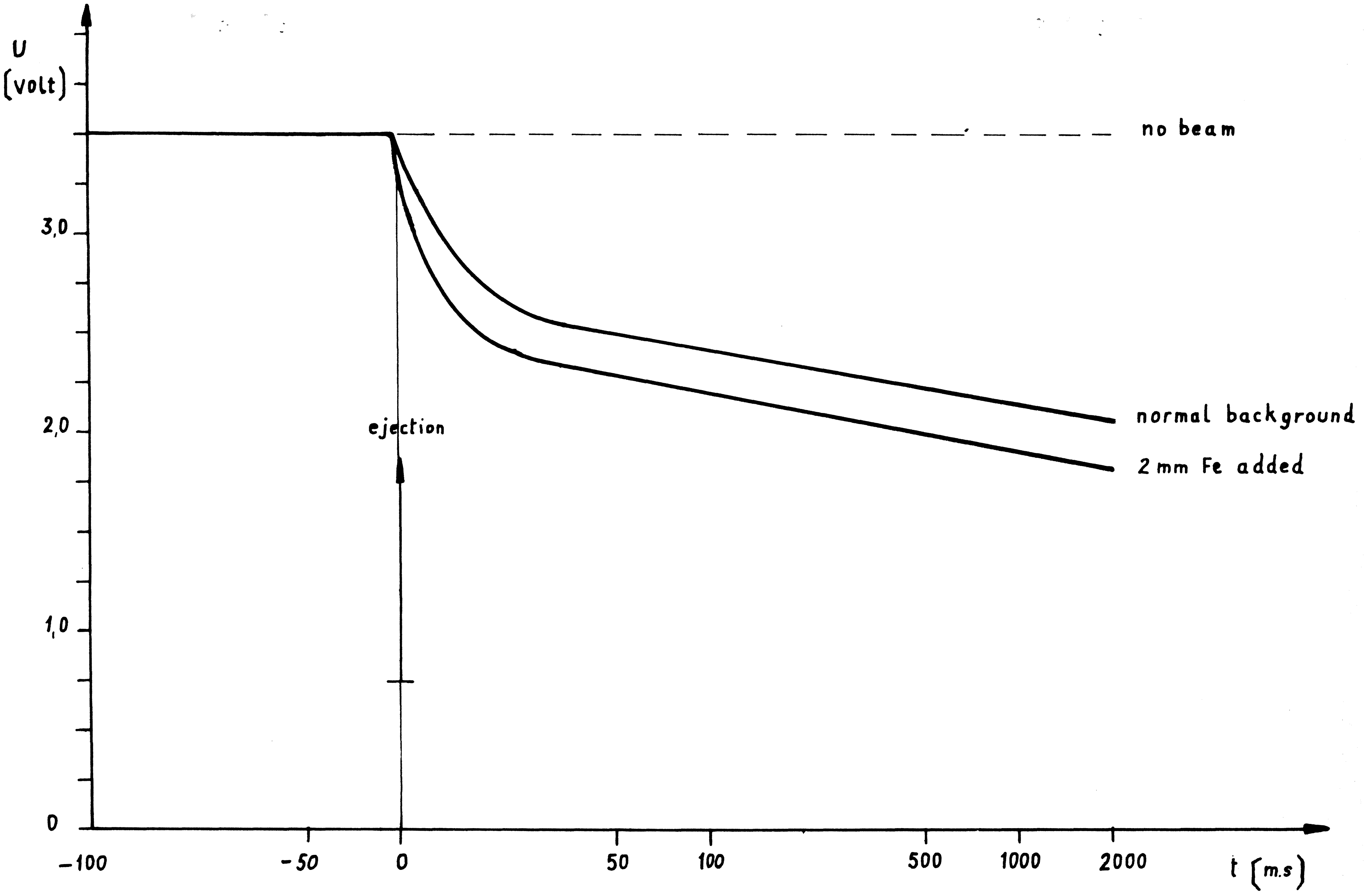

wire
~50cm
apart
beam
1m
memory cable
①
30m
discharge line
②
Z₀
U_{IN} = 9,5 Volts
①
②
Δt
ejection

Fig. 3



Leakage of 2 prototypes with different impedance

Fig. 4



Leakage of charge on 125 Ω Hg storage line

Fig. 5

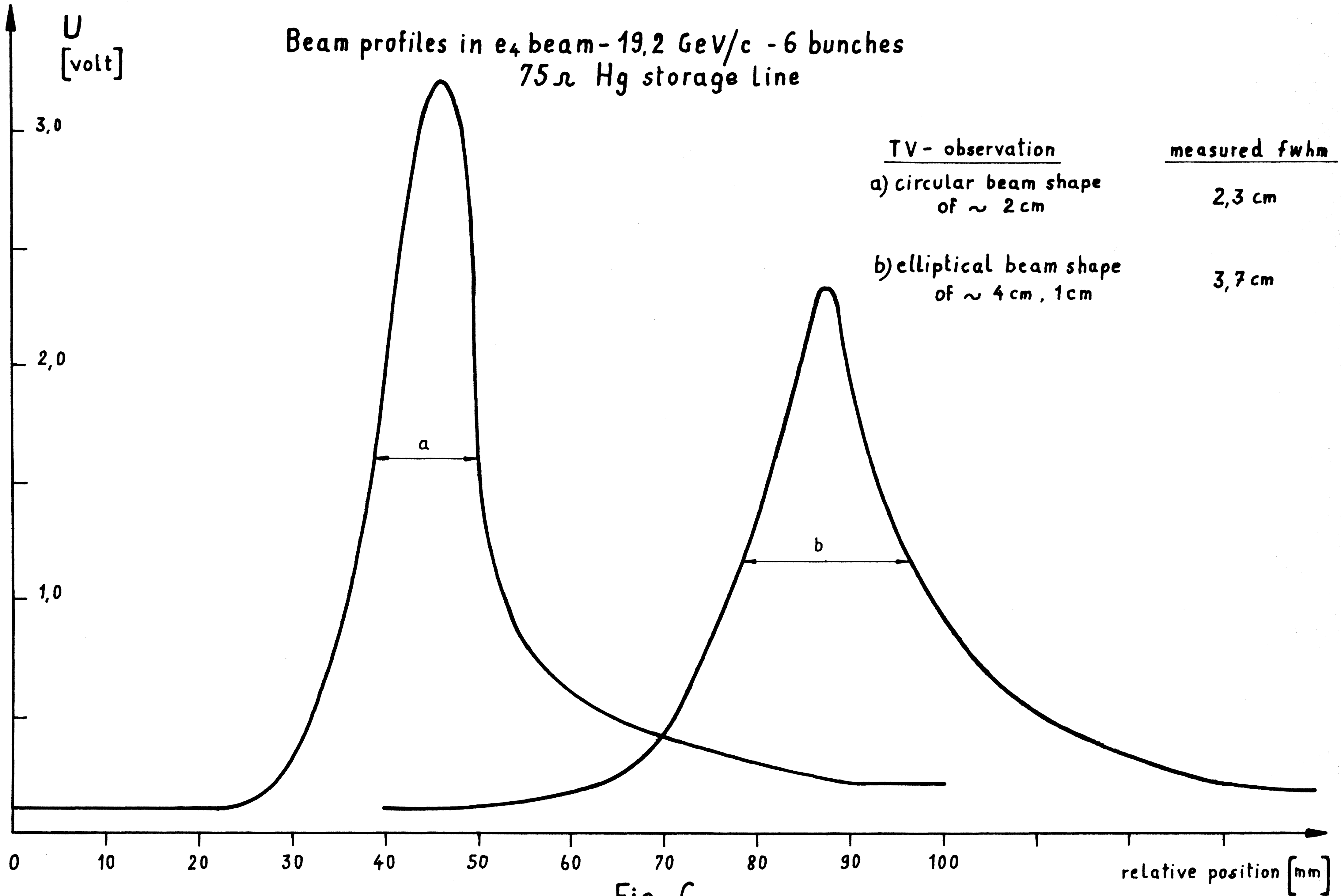

Beam profiles in e₄ beam - 19,2 GeV/c - 6 bunches
75 Ω Hg storage line
U [volt]
3,0
2,0
1,0
TV - observation
measured fwhm
a) circular beam shape of ~ 2 cm
2,3 cm
b) elliptical beam shape of ~ 4 cm , 1 cm
3,7 cm
a
b
0
10
20
30
40
50
60
70
80
90
100
relative position [mm]

Fig. 6

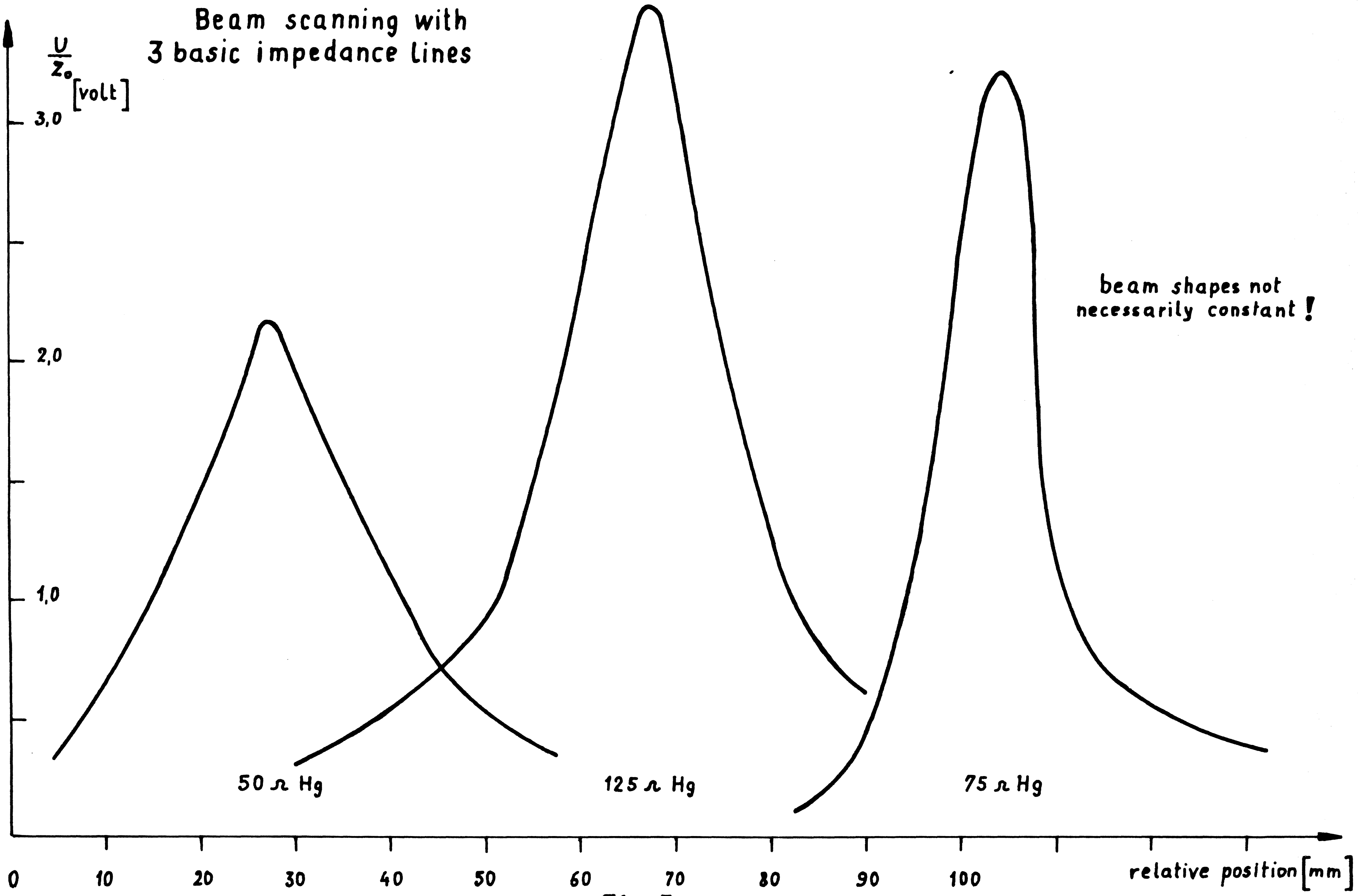
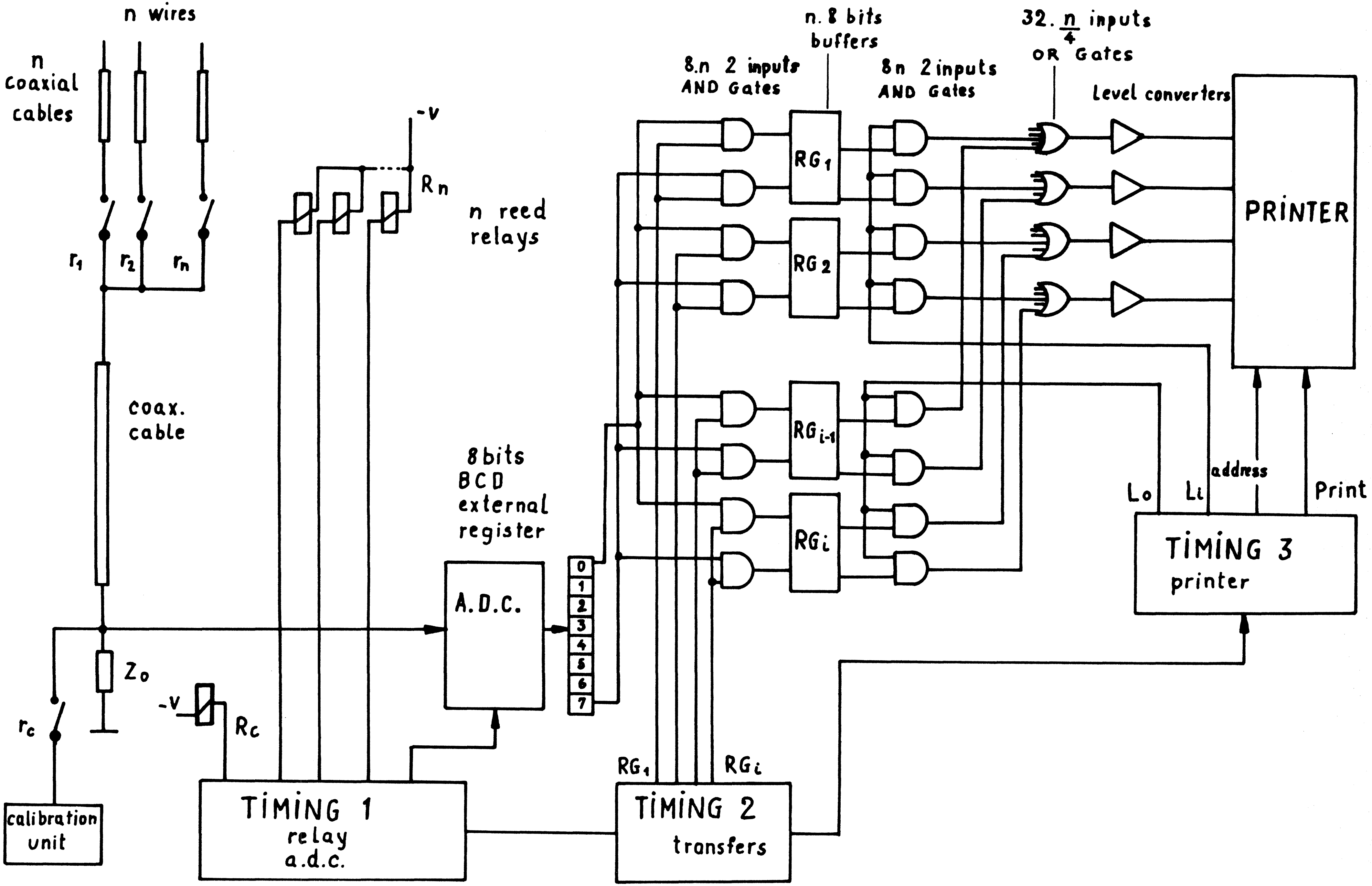
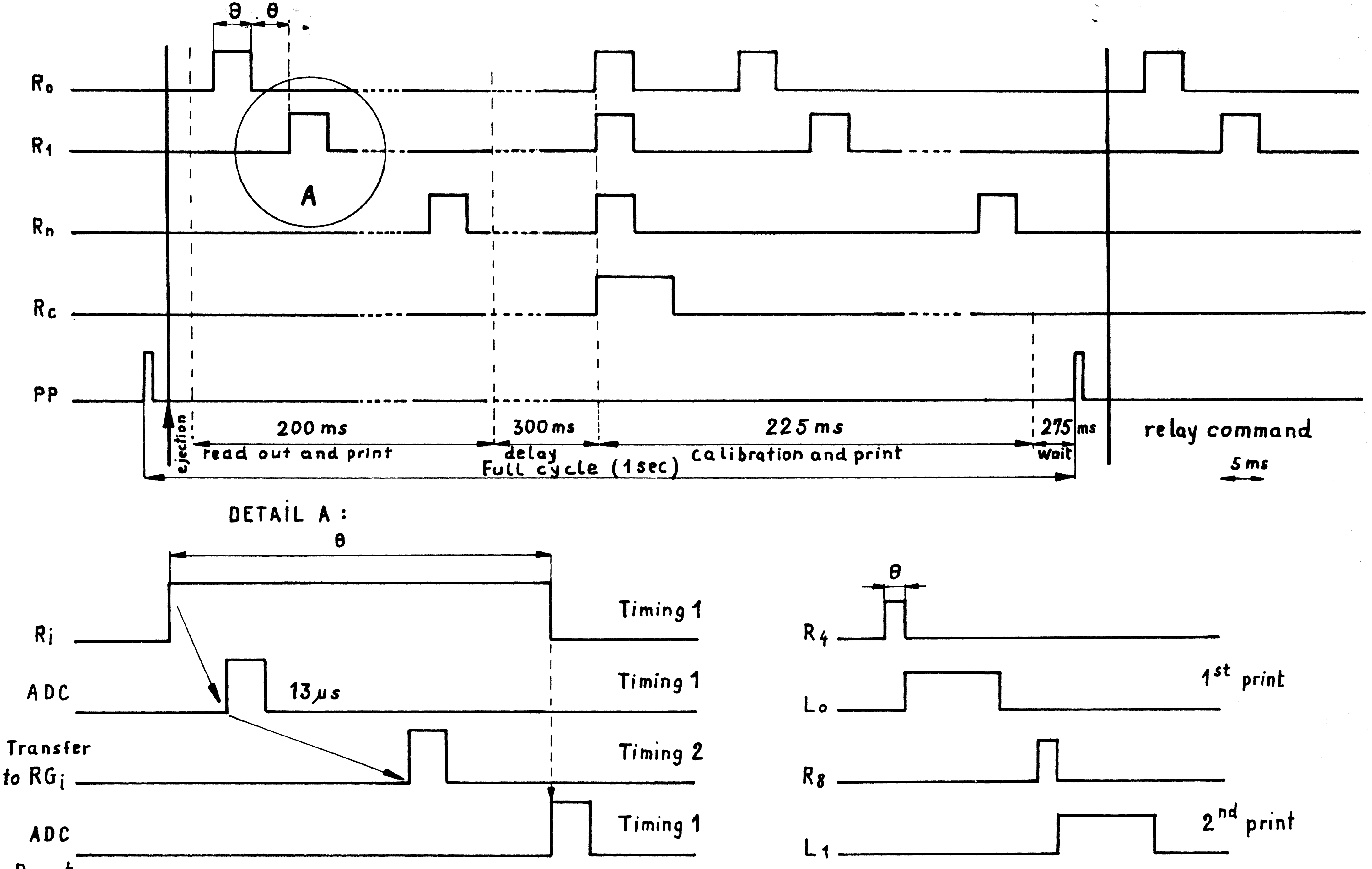

Beam scanning with
3 basic impedance lines
U/Z₀ [volt]
3,0
2,0
1,0
0
10
20
30
40
50
60
70
80
90
100
relative position [mm]
50 Ω Hg
125 Ω Hg
75 Ω Hg
beam shapes not
necessarily constant !

Fig. 7



General block - diagram

Fig. 8



ADC commands - transfer to buffers RG_i during a R_i - pulse

Printer commands by TIMING 3

TIMING

Fig. 9