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EXPERIMENT : Measurement of $\bar{p}$ yield with a conducting target

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The aim of the experiment was to replace the standard target and horn assembly by a conducting target and horn electrically in series in order to measure single shot $\bar{p}$ production yields in AA, and compare these results with computer modelled calculations. This experiment, made in the frame of the long term improvement programme of AA, was designed, by minimizing modifications to the existing set-up in the AA target area, for a rapid return to the normal situation without damage to existing equipment and with a minimum radioactivity dose for the staff involved. This has the drawback of having only one parameter free (the horn-target current) to adjust at the same time the focusing by the horn and the matching by the horn and target.

The conducting target itself is a copper rod of 3 mm diameter, embedded in small blocks of graphite, surrounded by an insulator and a coaxial housing in aluminium alloy (Fig. 1). Small ducts are machined in the graphite to facilitate efficient gas cooling as close as possible to the heat source. For the experiment, nitrogen gas was chosen as it avoids any combustion of the graphite (i.e. carbon) and compressed nitrogen bottles were simply discharged at 8 bars into the conducting target device through an electrical valve. The target was connected electrically in series with the standard horn through a coaxial structure to provide the necessary drift space needed between the $\bar{p}$ source and the focusing lens. A thermocouple was placed in the gas exit tube to measure the gas temperature which was recorded in the control room. The sandwich line to feed the horn and target were of the quick-disconnect type (design and prototypes were made in the EP Division).

The lifetime of a conducting target subjected to the shock of the proton beam at the same time as it is being pulsed by the very high magnetic field and heated by the electrical current, was not known. Targets in various materials were prepared: copper, W-Cu mixture, W-Ni-Fe alloy) in various lengths and diameters. The first target chosen for the experiment was:

- Copper 3 mm diameter,
- 100 mm length + flanges → 122 mm,
- Drift space : 186 mm.

Results with the first conducting target (Exp. 13a)

The AA machine was first put into operation after the shut-down and the trimmings of the important parameters were then made, (and yields of 6 to 6.5 × 10^{-7} $\bar{p}$/p recorded). Next the conducting target and horn were installed and yields measured. It was soon noted that the proton beam was not in good shape: the intensity was less than 4 × 10^{12} p/pulse instead of the usual 1.2 × 10^{13} and perhaps more disappointing the beam spot on target was wider than normal and asymmetric. The variation of the yield measured by the Schottky scan method versus the target-horn current is shown in curve 1, Fig. 2. The maximum yield occurs with a low current of 100 kA (the common value for the horn with a passive target is ≈165 kA). After steering optimization we tried to find the optimum trigger timing but due to lack of beam stability and jitter in yield measurements, the intensity optimization necessary for each new timing has given only a small improvement in the best yield measured at 7 × 10^{-7} $\bar{p}$/p. Changes in the settings of the proton beam transfer quadrupoles (focus moved by -10 cm and small changes in the $\beta_{H,V}$ values) gave insignificant variations in the results, even though the proton beam intensity had in the meantime been raised to ≈9 × 10^{12}. With the latter intensity there was no apparent improvement in proton beam emittance, and in view of the reliability of the copper target in this test we have decided to go to the second test also with a copper target instead of the supposedly more resistant materials containing tungsten.

Results of the second test (Exp. 13b)

The new geometry was:

- Copper 3 mm diameter.
- 88 mm length + flanges → 100 mm,
- Drift space: 166 mm.

The main reason to go to a shorter target was the defocusing effect inside the target of the proton beam which results in side losses of protons before the end of the target has been reached. Another reason was that the value for the maximum yield was lower than calculated, which could be explained by a higher than estimated reabsorption of the $\bar{p}$'s inside the target.These two effects lead to a lower optimal length.

The results are given in curve 2, Fig. 2: they show no significant change except that the optimum yield was, as foreseen, obtained for a slightly higher target-horn current; octupole setting, proton beam steering and optics were made but without any noticeable improvement. Only the $\bar{p}$ transfer line (downstream of target) optics, being rematched to the so-called "100Π" settings, gave a better yield of 7.7×10^{-7} $\bar{p}/p$ (curve 3, Fig. 2). Changing this "match" even more radically led to the best yields recorded below:

"120Π" ($\beta_{H,V} \approx 3.30$ m at horn exit) → 7.8×10^{-7} $\bar{p}/p$.
"140Π" ($\beta_{H,V} \approx 2.86$ m at horn exit) → 7.9×10^{-7} $\bar{p}/p$.
"100Π" ($\beta_{H,V} \approx 2.89$ m at horn exit) → $8. \times 10^{-7}$ $\bar{p}/p$.

It is worthwhile mentioning that these values were obtained consistently over many shots without reoptimizing the other machine parameters, except the voltage on the horn/target power supply which was raised to give 115 kA (see points in Fig. 2).

Temperature measurements were made throughout the tests mainly to control the nitrogen cooling. Comparative measurements were made with beam and without showing that the heat deposited by the beam (8.5×10^{12}) was ≈4.6 higher than a 115 kA pulse (Fig. 3).

Discussion of results

a) Proton defocusing: an emittance measurement made in the PS* during the second test gave $4.4\pi \times 10^{-6}$ rad.m for 95% of the beam. Supposing this emittance is not further enlarged through extraction and transfer, this gives a beam radius of 1.3 mm at entrance of the target (radius 1.5 mm) and 1.88 mm at exit due to the proton defocusing effect. Therefore, a 3σ radius would be 1,6 mm at entrance and 2.3 mm at exit: a significant percentage (~10%) of the proton beam was lost radially

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and did not interact with the target. Our attempts to change the proton beam transfer line optics were irrelevant as they were unable to make sufficient changes to the β slope at entrance to get the necessary β at exit (with the large emittance present) of the target. In future we should try to have more control over the emittance of the proton beam used for conducting target tests (by e.g. SEM grids). The maximum emittance is given by $\varepsilon \simeq r_c^2/\beta(I + K\ell^2 + \ell^2/\beta^2)$ with r_c = target radius, β = betatron function at entrance, $K = G/B\rho$ (G = gradient), ℓ = target length. For instance, a 2 mm diameter, 100 mm length and 110 kA intensity would give a maximum allowed emittance of $0.9\Pi \times 10^{-6}$ rad.m. This is far beyond what can be achieved and a test of a 2 mm target was postponed for this reason (and others).

b) Antiproton trajectories: an examination of $\bar{p}$ trajectories inside and outside the target is interesting (Fig. 4). With the best measured yield, production angles up to 43 mrad may be captured inside the target. From 43 mrad to 57 mrad outgoing $\bar{p}$'s probably still fall inside the acceptance of AA. These $\bar{p}$'s suffer less reabsorption than the smaller angles as they do not traverse the whole length of the target but only cross the target end flange. This fact is confirmed by the changes that were necessary in $\beta_{H,V}$ at horn exit to get the highest measured yield. A source radius of ~2.4 mm corresponds to these "outside-target" trajectories.

The relatively low current intensity in the horn implies a focus onto the first part of the target instead of its downstream end. The possibility of trimming the horn current independently of the target current would have been useful.

Conclusions

The gain in yield of $\bar{p}$ production in AA was measured to be 25 to 30% but is not the best we can hope to get from the optimum design which includes better focusing of the proton beam. This gain does correspond to the calculated (Monte-Carlo program) relative gain with a conducting target compared with a standard target as is shown in 1). The proton beam defocusing in the target is not under control with the present proton transfer line. The $\bar{p}$ beam transfer line has to be matched to the peculiar aspect ratio of the emittance shape: this was not fully achieved in these tests.

In view of the conditions of these tests, it is believed that the conducting target is one of the few ways to get a higher $\bar{p}$ production density in phase space and that an operational and reliable design should now be looked at.

Reported by J.C. Schnuriger

1) Antiproton production and collection for the CERN Antiproton Accumulator. E. Jones, S. van der Meer, F. Rohner, J.C. Schnuriger, T.R. Sherwood. 1983 Accelerator Conference, Santa Fe.

2) Pulsed target test at the CERN-AA. A calculation of expected p yields. C. Hojvat, A. Van Ginneken. Feb. 1st, 1983. Fermilab draft note.

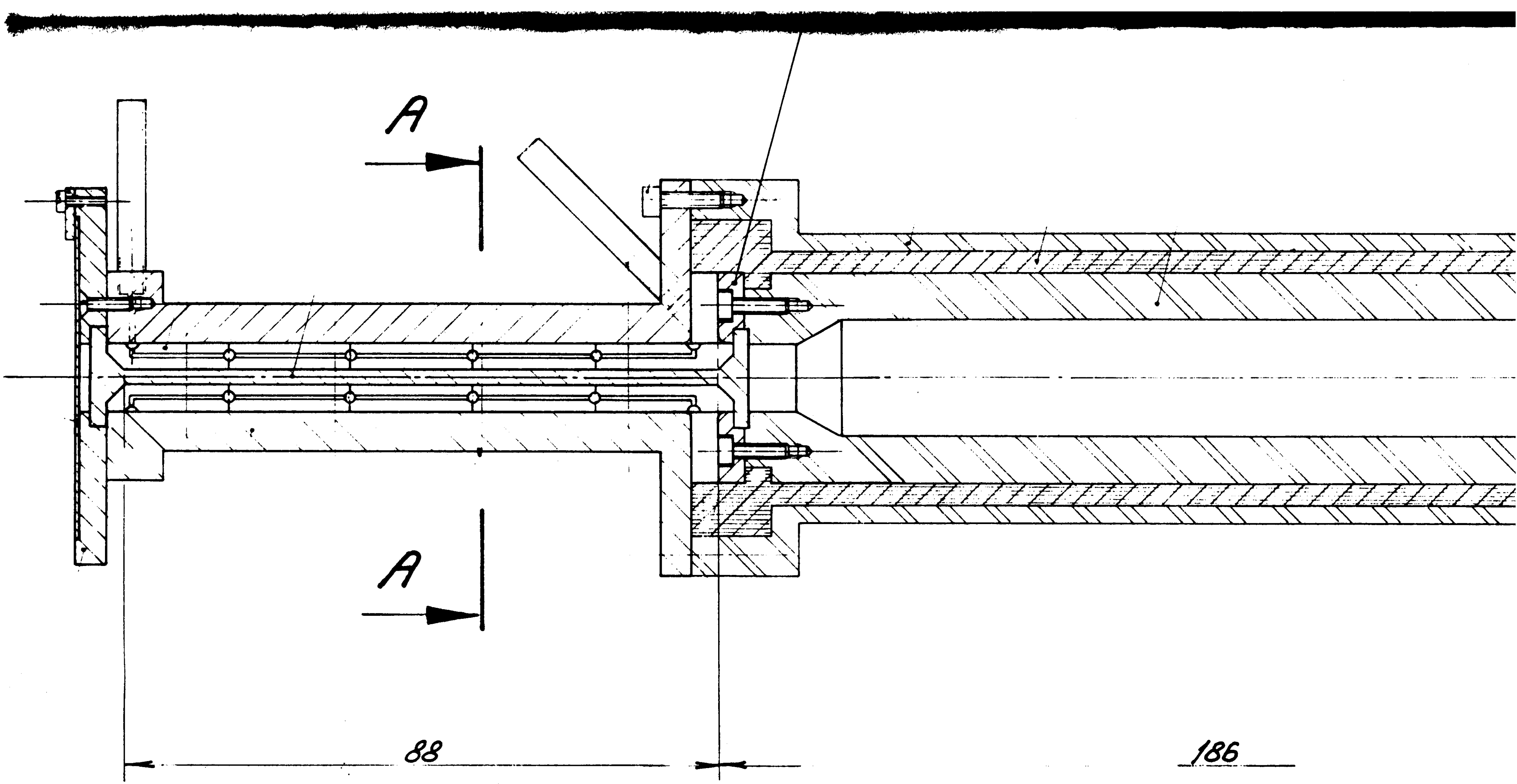

Fig 1 Conducting target

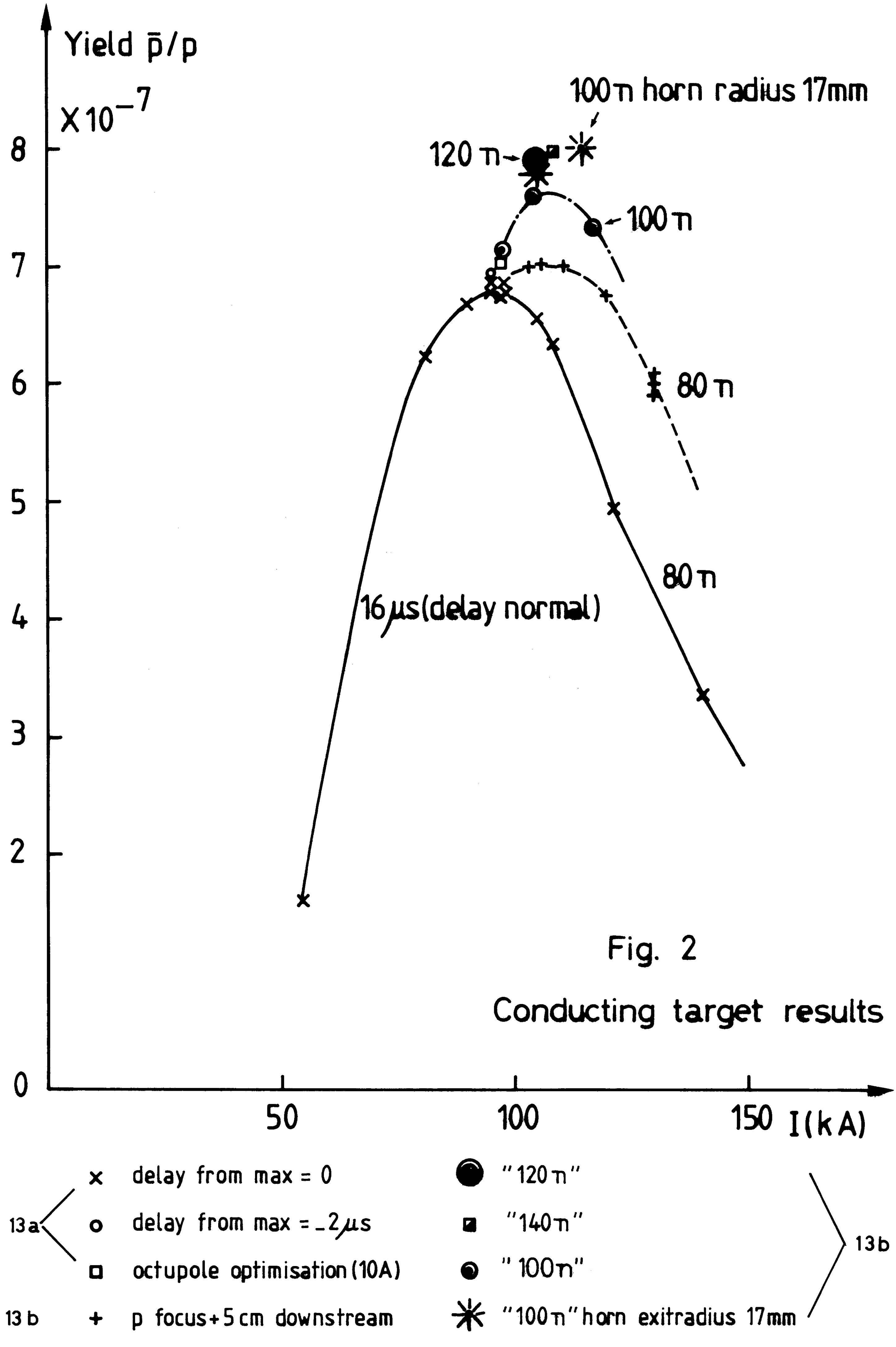

Fig. 2

Conducting target results

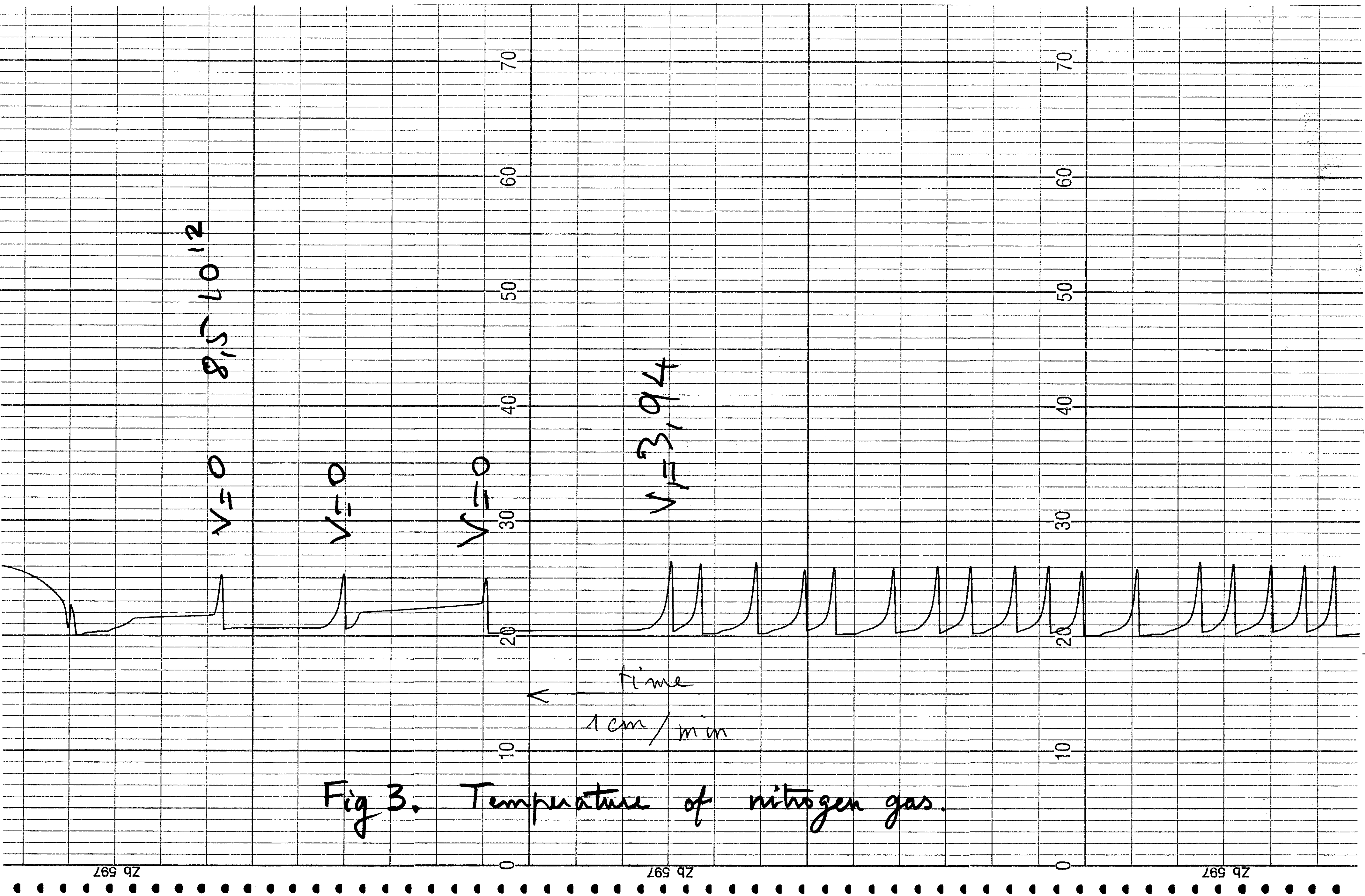

Fig 3. Temperature of nitrogen gas.

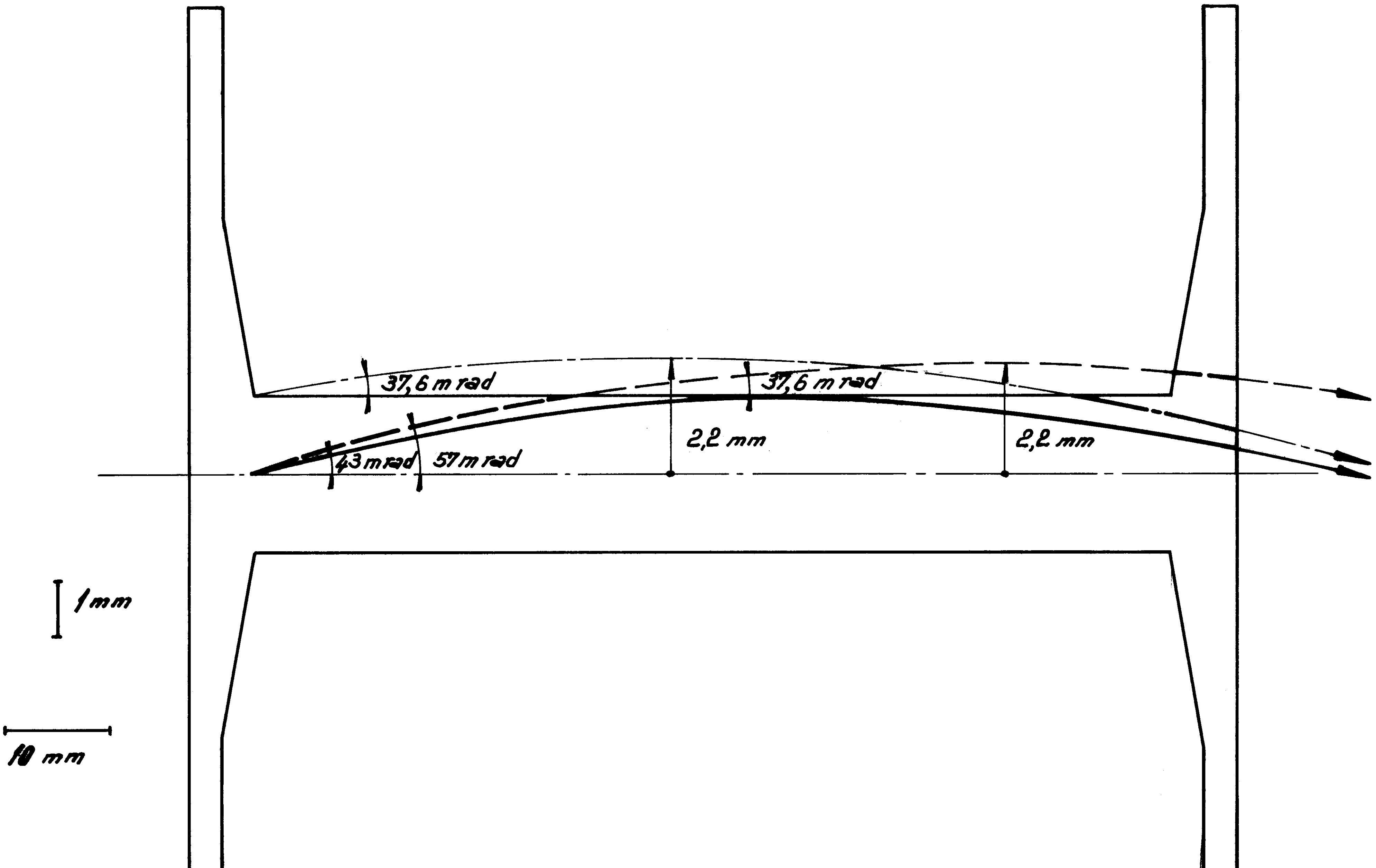

Fig. 4

Conducting target typical trajectories
I target = 110 kA