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PRODUCTION OF SECONDARY BEAMS AT CERN PROTON SYNCHROTRON

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(presented by W. Richter)

I. Introduction.

When the CERN 25 GeV proton synchrotron was finished late in 1959 two methods of external beam production were envisaged. One of these was the use of internal targets, the other an ejection scheme [B. Kuiper and G. Plass (1); F. Krienen (2)] . The latter is under development. Internal targets have now been in use for 18 months and a certain amount of progress has been achieved. This paper discusses some of the aspects of target technique in relation to an alternating gradient proton synchrotron.

It may be useful to repeat first a few general characteristics of the CPS. This strong focusing machine, which accelerates protons up to 28 GeV maximum, has a vacuum chamber with an internal clearance of 146 mm horizontally and 70 mm in height. It accelerates about $2 \cdot 10^{11}$ protons per cycle and keeps these at full energy during a "flat top". A few standard machine cycles are given in the following table :

TOP ENERGY (GeV)	REPETITION RATE (s)	FLAT TOP LENGTH (ms)
28	5	20
24	4 3	200 50
20	3 2	300 50
17	2	300
10	1	50

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The beam diameter at the end of acceleration is about 8 mm, and its radial position can be chosen within a range of about 70 mm. The reproducibility of the beam position from cycle to cycle is of the order of 0.2 mm. During acceleration, the beam consists of 20 bunches, each having a length of about 10 ns, and the distance between centres of bunches is 105 ns. The revolution time is 2 μs. Further details of the machine are given by E. Regenstreif (3) and some aspects of its utilisation as a Nuclear Physics tool are discussed by M.G.N. Hine (4).

The targets required for this machine are rather small. Their total weight lies in the range of 1 to 100 g, from 5 μ foils up to 15 mm blocks being used. A 5 μ aluminium foil has given a burst length of 200 ms which corresponds to 10^5 traversals or a total path through material of 500 mm. This value is about twice the nuclear mean free path length, which is known to be 270 mm for this material. - Two extreme cases can be cited : The production of long bursts, for counter experiments, requires a very small amount of material in the beam, in order to get a burst length of say 50 ms. For bubble chamber experiments, on the other hand, one needs a secondary beam pulse of 1ms and less, which requires a larger mass to be brought into the beam. Besides this, one must have a suitable monitor system to determine the burst shapes of the secondary beams produced.

A general view of the target units which have been developed for the CPS is shown in fig. 1. Each unit has two independent flip targets and can be fitted into any of the 100 pump manifolds around the machine. The mechanism consists of a small magnet, which pulls the target head into the working position via a band inside the tube. Springs are used to decelerate and return the head into its rest position. Small contacts are employed to indicate the target position. The supporting rods can be moved radially with a motor-drive, and a potentiometer indicates position. In fig. 1 the lower rod has a foil target for long bursts, and the upper one a fast target which cuts through the beam rapidly to produce short secondary bursts.

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The monitor system consists of single Čerenkov counters, which "look" at the targets in use. It was found possible, to obtain the same burst shape as seen with a counter telescope system placed in a selected beam. By choosing appropriate integration time constants, one can display either the true burst shape or an integrated signal.

II. Long burst production.

Three standard target types are now in general use (fig.2) :

a) foil targets of Be or Al with normal thickness of 50 μ

b) vertical wire targets of Al with 0.5 x 0.5 mm^2 cross section

c) point source targets of about 3 mm diameter, made of Be or Al wire pointing in the direction of the secondary beam.

The requirement for the last type began with the use of separators in secondary beams, eding a very small source.

All those long burst targets are operated during the flat top of the magnet cycle. They are flipped into a position close to the outer radius of the beam just at the beginning of the flat top. At the same time the beam is debunched by stopping acceleration. This is done by applying a jump to the acceleration frequency, so that it is no longer in synchronism with the protons. The slope of the "flat" top is made slightly negative, so that the beam spirals on to the target. The burst shapes resulting from this procedure are shown in fig. 2. Up to a certain point, the burst length can be adjusted by altering the slope of the magnetic field flat top. A further increase by a factor of 1.5 to 2 was obtained by applying the radial bunch broadening technique, which has been explained by H. Fischer (5). In addition this procedure improves the burst shape, which becomes nearly rectangular. The modulation on all these burst shapes is due to the 600 cycle magnet current ripple, which will be suppressed in the near future by using a filter during the flat top.

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In order to compare different target heads, e.g. different materials, or different shapes, a six-head target has been developed (shown in fig. 3). With this mechanism, the heads can be interchanged between machine cycles according to a preselected sequence. This is done by a small motor via a special gear. All the targets interrupt the beam at the same azimuthal and radial position.

III. Short burst production.

There are three different possibilities: The most elegant method is to place a rather thick target close to the beam and push the beam on to the target by exciting betatron oscillations. This can be done with the "radio frequency knock out". [M.Geiger (6)] , a deflection field (magnetic or electric) of high frequency, which has a certain relation to the acceleration-frequency. Short bursts, with fairly complete beam consumption within 100 to 300 μs, have been successfully obtained.

For beam sharing, using part of the beam for a long counter burst later in the cycle, a target finger cutting through the beam has been found easier to handle and therefore more frequently used. Such a target has been shown already in fig. 1. Some more information about this operation is given in fig. 4. The intensity of the secondary beam can be adjusted very easily by changing the radial position of the target, so that the finger then cuts only part of the beam. Its velocity whilst passing through the beam is 20 to 30 mm/ms. The burst length is 300 to 800 μs for a consumption of between 1 and 35 °/o of the primary beam. The time jitter, which is very important, was less than 200 μs. As mentioned above the remaining part of the beam can then be used for a long counter burst later in the cycle.

A very interesting phenomena of this "cut through" procedure is the fact that the beam "jumps" towards the machine centre more than 2 mm during the time of the fast burst. This is due to the energy loss of the protons, which requires several milliseconds to be restored by radio frequency acceleration. This behaviour, which is shown in fig. 4, can be used for a third method of producing short bursts and is especially valuable

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if a point source target is wanted for a refined optical system. The point source target (thick wire pointing in direction of secondary beam) is placed very close to the inside radius of the beam and a fast target is flipped through the beam somewhere else in the machine. Simultaneously one can steer the beam on to the point source target with the RF control. With very careful adjustment of the timing, the burst length for the point source target is less than 1 ms for 90 °/o of total burst intensity. *)

IV. Programmed target operation.

The target control system is capable of operating several targets according to a preselected programme. This is of special interest for counter experiments involving comparison of target materials, or for cloud chambers, which do not require more than one out of every 200 machine pulses. Connected with this is the distribution of "warning" pulses and the control of other functions and apparatus (e.g. beam position, external bending magnets, primary and secondary beam shutters).

V. Source size and efficiency.

Taking the finger of the fast target as driving mechanism, we succeeded in flipping l rge thin foils into the beam at a rather high velocity. The total weight of those foils including their frame has been in the order of 1 g. With aluminium foils of 5 or 10 μ thickness the vacuum chamber aperture is almost completely covered within a fraction of the total burst time. The acceleration frequency is left on in order to compensate for energy losses in the target. Hence the protons are lost only by absorption and scattering. It may be of interest to show the activity distribution of an aluminium and a gold foil, which have been used in this way and measured later on from a radioautograph as shown in fig. 5. With this method, we are able to determine the size of the source for secondary beams from foil targets. In aluminium, multiple scattering is small enough

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*) This was used to produce 2 to 3 stopped antiprotons in a bubble chamber for a circulating beam of 1.5 10^{11} protons and 100 °/o beam consumption.

to permit the determination of the total cross-section, for absorption plus diffraction scattering, from the initial decreasing slope of the burst shape and to deduce the quantity of multiply-scattered protons from its continuation, thus giving the target efficiency [J.A. Geibel (7)]. The first results have shown an efficiency (number of absorbed and single scattered protons versus number of protons in primary beam) of about 60 °/o for those big foil targets, which should be the most efficient ones.

VI. Beam Dumping.

In many experiments it is desirable to avoid protons hitting the vacuum chamber wall in the vicinity of the targets. This can be done by using dump targets in different azimuthal positions in the ring. An effective dump target should have a considerable length (e.g. half a metre of steel), in order to be sure that the particles scattered out from the dump target do no harm. Therefore, the best solution seemed to be to use the vacuum chamber wall itself as a dump target. There are ten pairs of kicker magnets, (dipole magnets producing horizontal perturbations) available in the CPS; for further details see E. Regenstreif (3). Energizing some of these in an appropriate way, one can change the closed orbit, as shown in fig. 6. On the side of the ring opposite to the target area the distance of the closed orbit from the vacuum chamber wall is then so small that most of the scattered particles are killed in the wall before they have a chance to hit the target again.

The result of this dumping technique is shown in Fig. 7 for a fast burst of full beam intensity. By using the dumps the long burst tail, which is produced by the scattered particles under normal conditions, disappears nearly completely, and the burst time becomes less than half of the normal value. This figure also shows two radioautographs of a pair of 7 μ gold foils which have been glued to an aluminium frame of 1 mm thickness. It can clearly be seen that by using the kickers the amount of irradiation of the frame is much less than under normal conditions.

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Acknowledgements.

A major contribution to target development has been made by Dr. Hine. In addition a large part of the CERN PS Machine Division has joined in the work on target techniques :

Dr. Reich started target development and brought into use the basic target system. Dr. Sluyters developed the counter monitors and made the whole target system work as a regular nuclear physics tool. Dr. Geiger designed the "RF-knock-out" system. Mr. Brooks developed most of the electronic equipment.

LITTERATURE :

1) B. Kuiper and G. Plass : "On the fast extraction of particles from a 25 GeV Proton Synchrotron". CERN 59-30.
2) F. Krienen : "Report on slow ejection system 25 GeV Proton Synchrotron" CERN 59-21.
3) E. Regenstreif : "The CERN Proton Synchrotron" (1st Part). CERN 59-29.
4) M.G.N. Hine : "Features of the CERN Proton Synchrotron of interest to experimenters". Lecture for Berkeley Conference Sept.1960.
5) H. Fischer : "CPS Operation at constant proton energy". Contribution to the Brookhaven Conference Sept. 1961.
6) M. Geiger : Basic relations concerning RF-excitation of β-tron oscillations in the CPS. CERN-PS/Internal report RF 59-2; 8.12.1960.
7) J.A. Geibel : Results of measurements with the fast large foil target. CERN-PS/Internal report Al 61-8; 22.2.1961.

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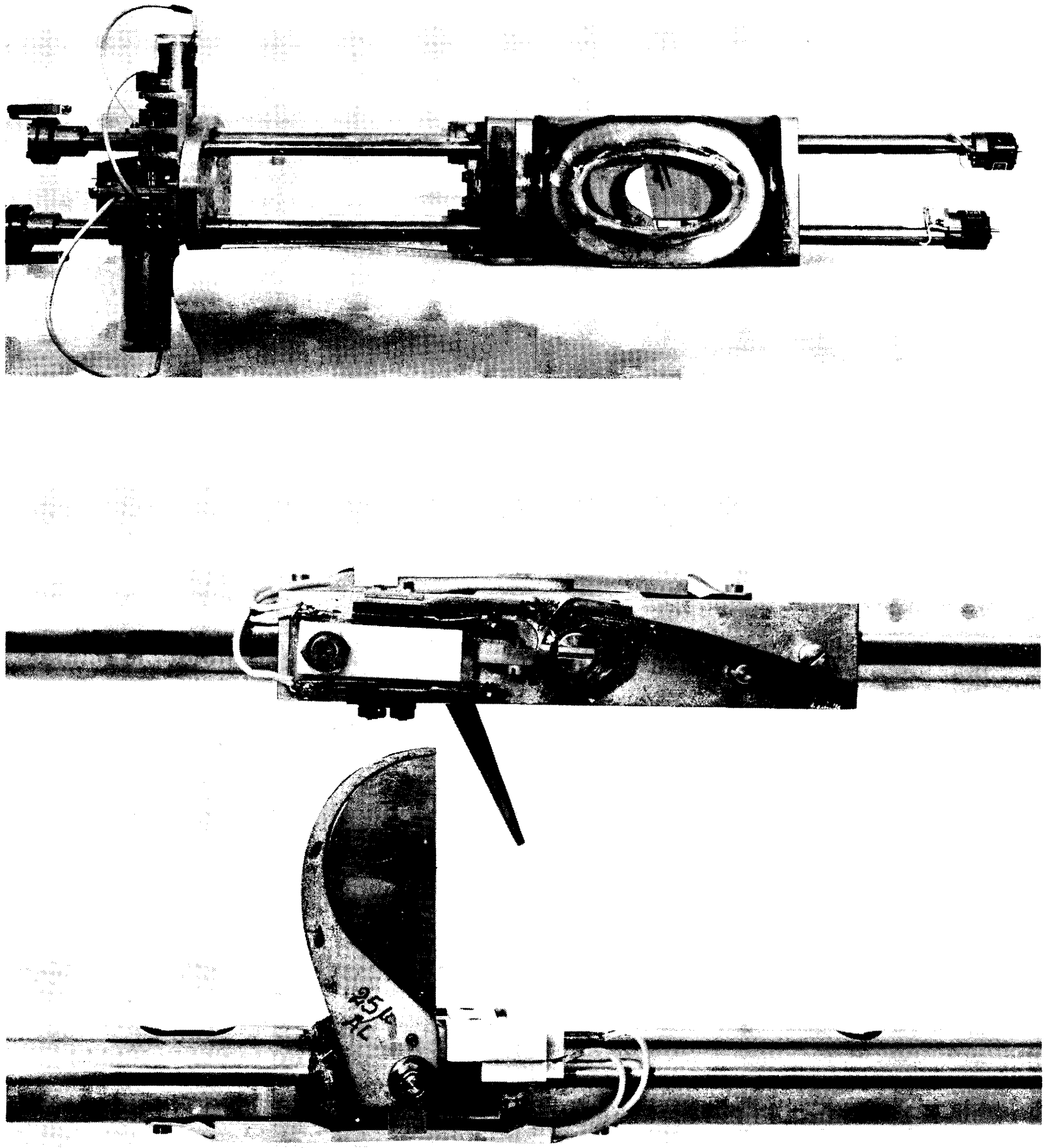


Fig. 1 Target unit

above: *mounted in pump manifold; target heads are seen through the clearance of the vacuum chamber; pulling magnets on the right; motor-drive for change of radial position on the left.*

below: *the actual targets enlarged; long burst foil target on the bottom rod; short burst fast target on the top rod.*

Objet: Subject: *Standard long burst shapes*	Nom - Name -	DATE: *23/5/61*

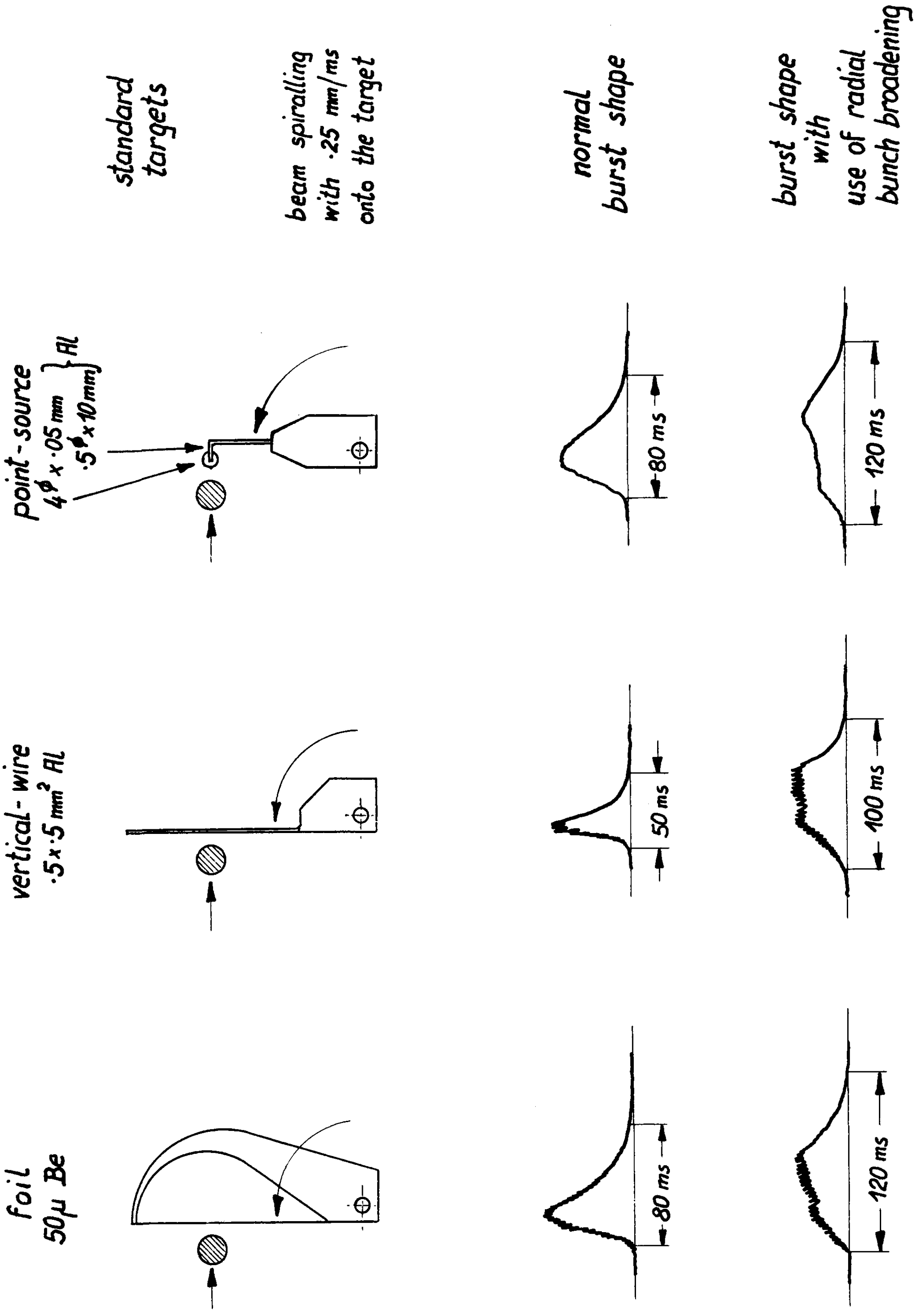


Fig. 2 Standard long burst targets

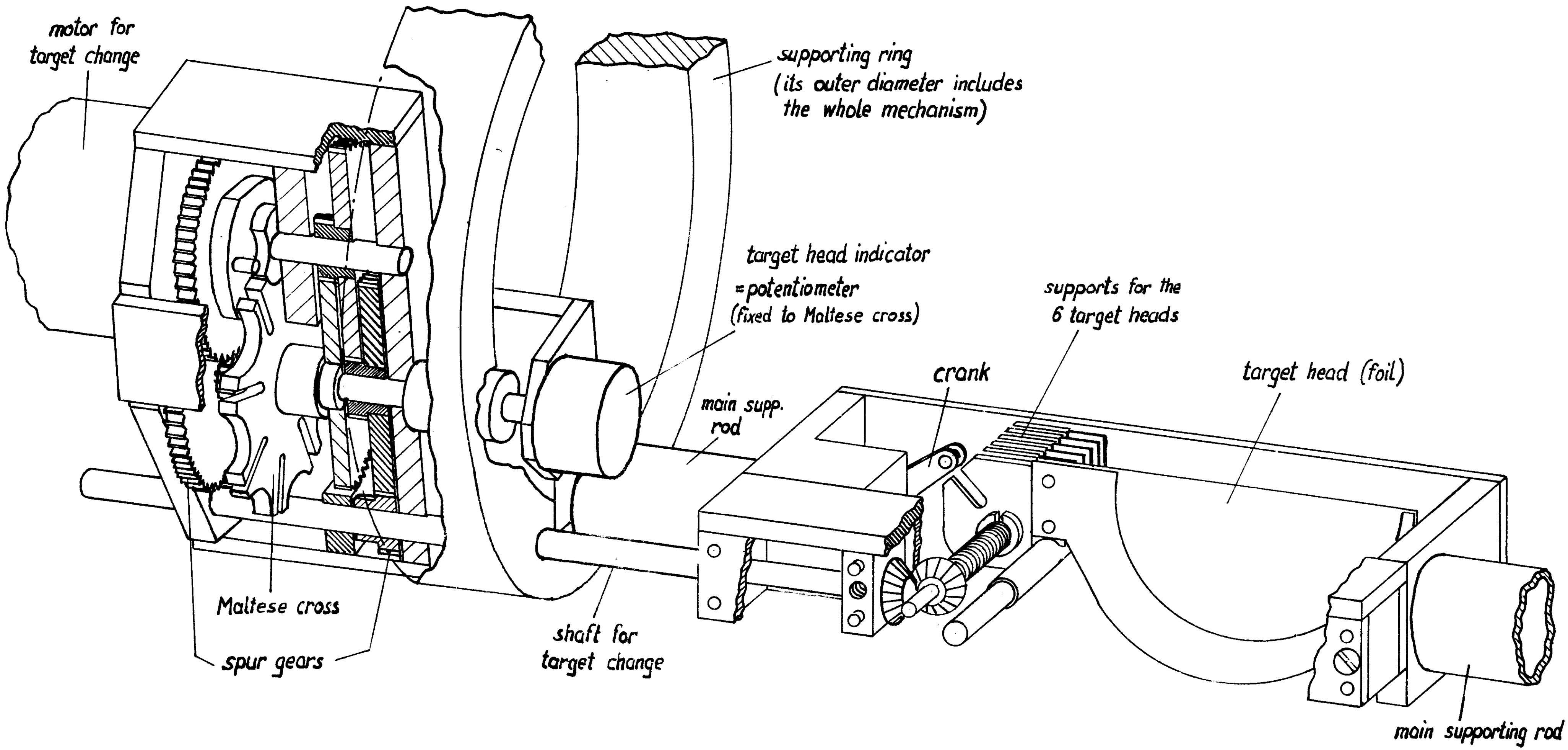
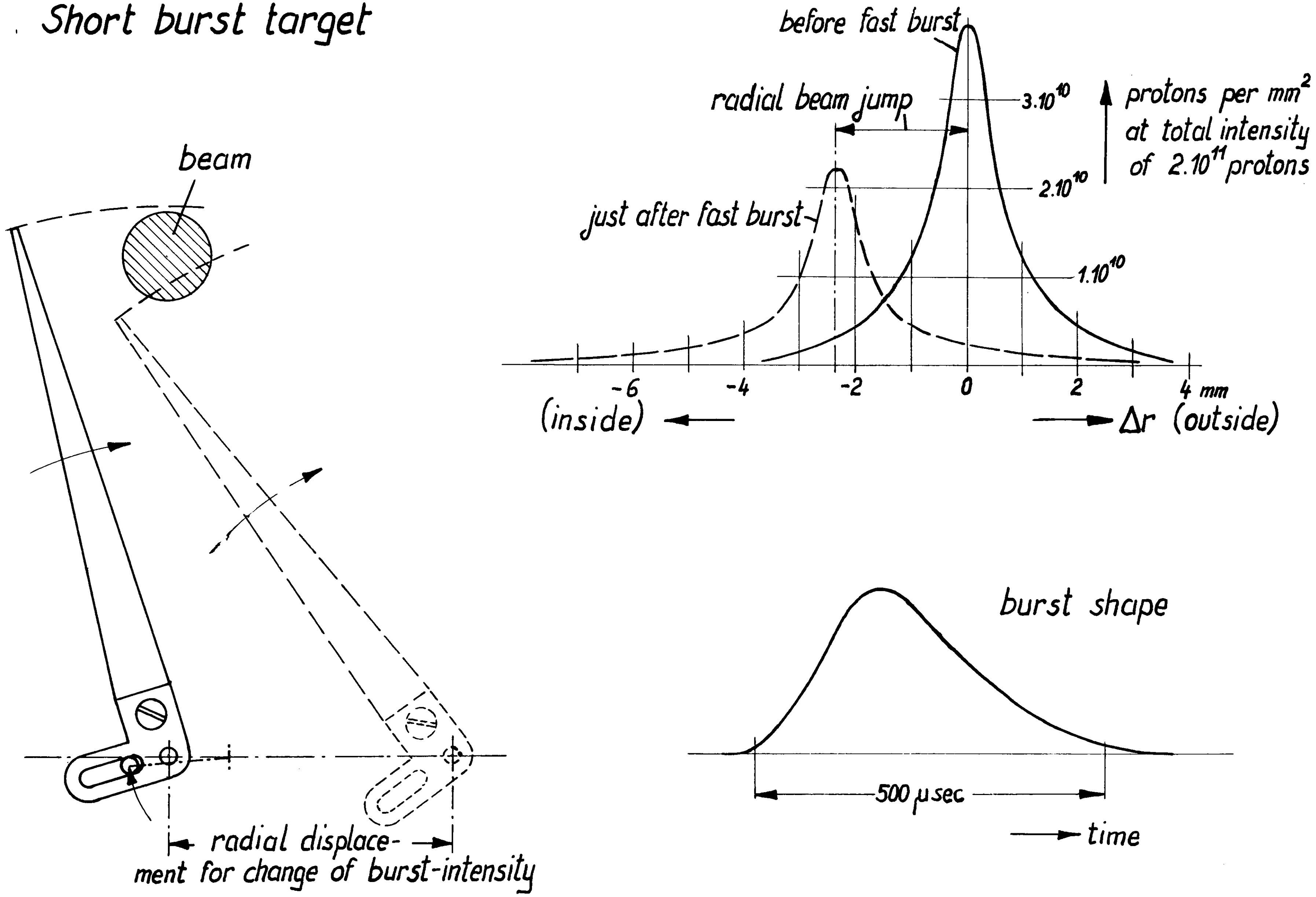


Fig 3: Mechanism of six-head-target, scale 1:1

The magnet, which is pulling the target by turning the crank, is not shown. All electrical connections and contacts (security devices) are ignored.

Fig. 4 . Short burst target



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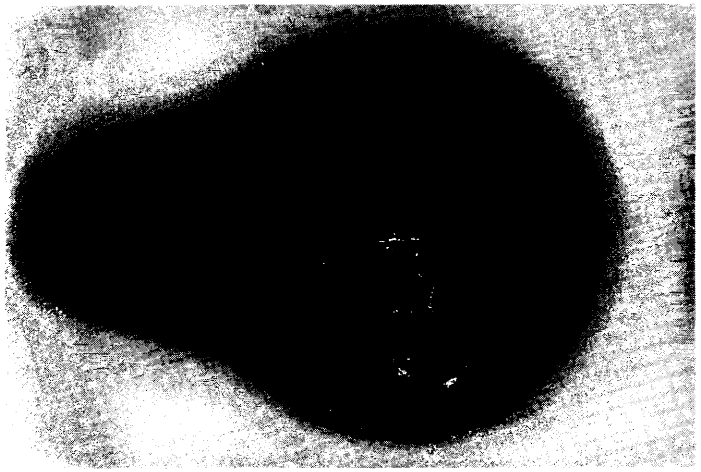
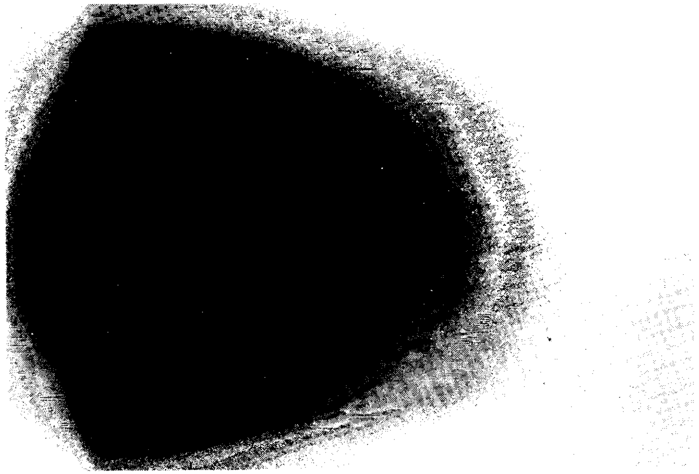
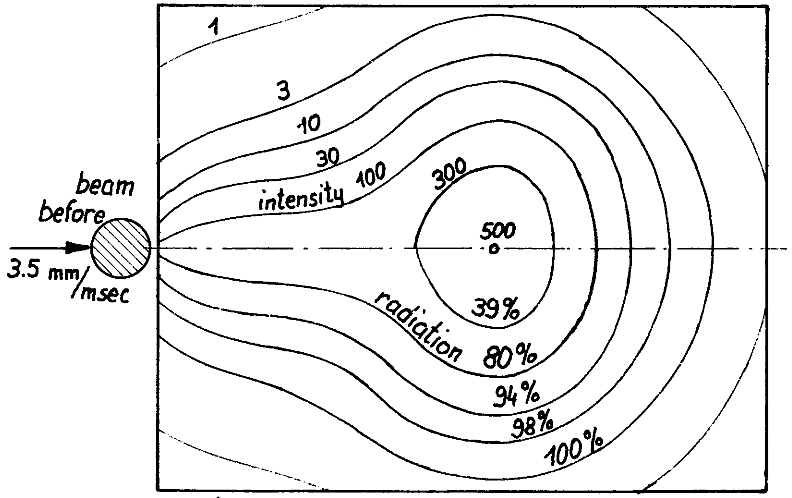
Radioautographs of irradiation at 24 GeV

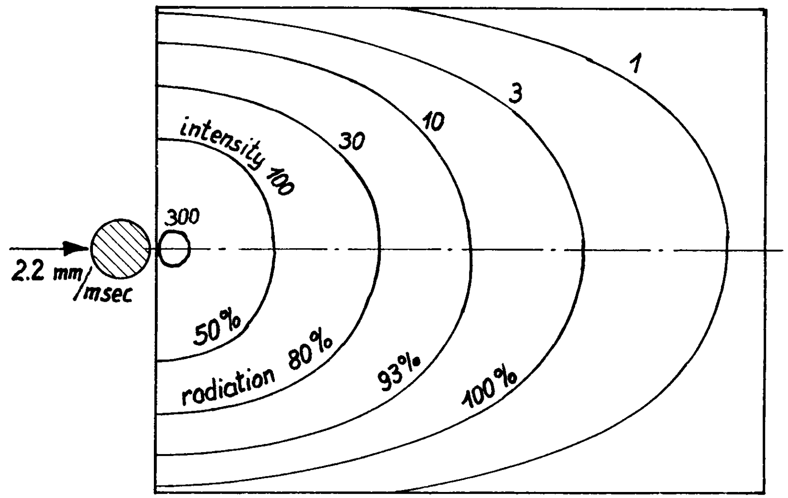




Source and intensity distribution



aluminium-foil 10 μ thick



gold-foil 7 μ thick

Fig. 5

Scale 1:1

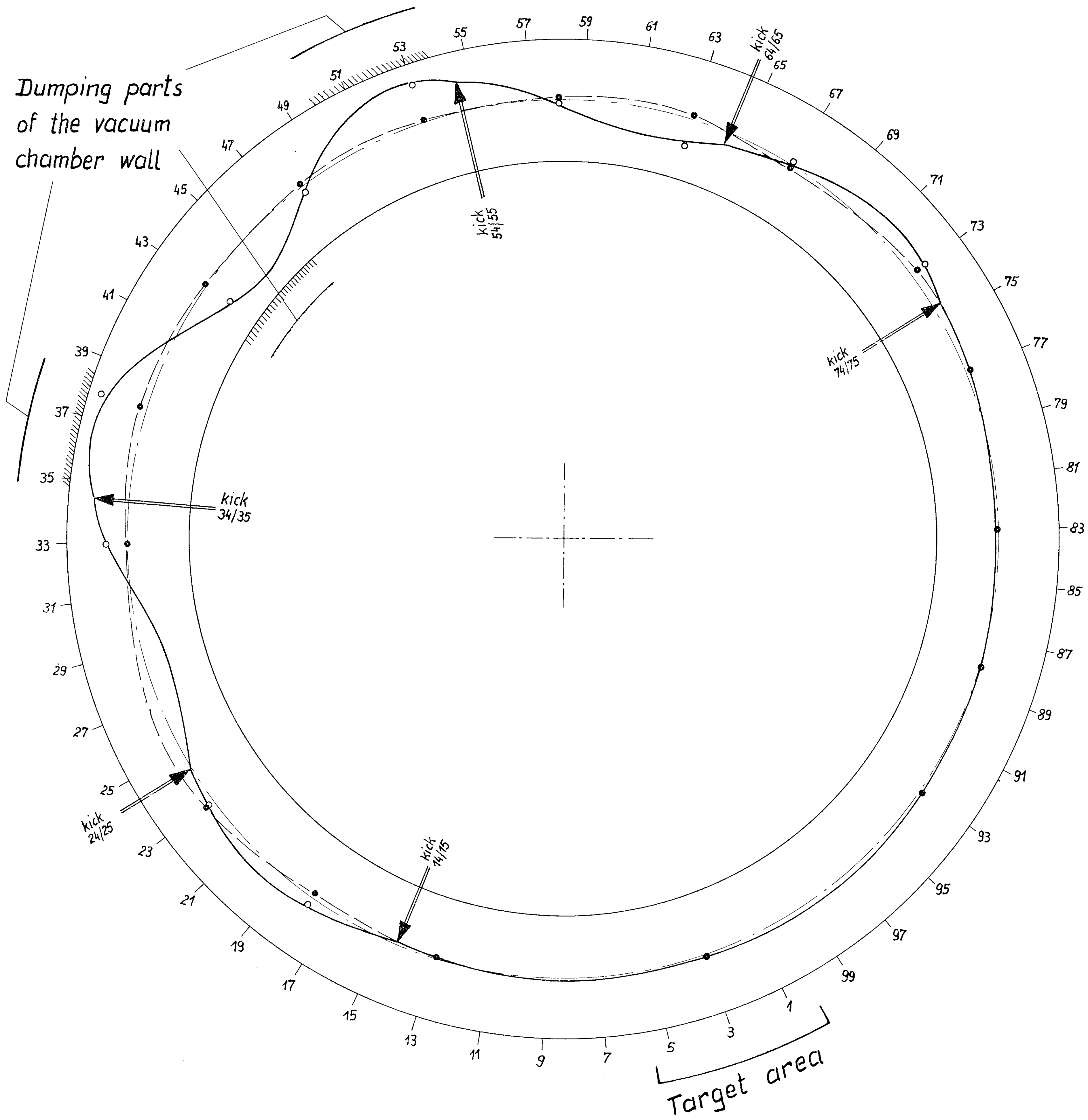


Fig. 6 Closed orbit deformation to dump scattered protons

Closed orbit on 16/4/61
at B_{10} = 700
pos. 106,5 at 20 GeV
kickers at 15 A
Scale 1 : 1000 (Δr : 1 : 5)

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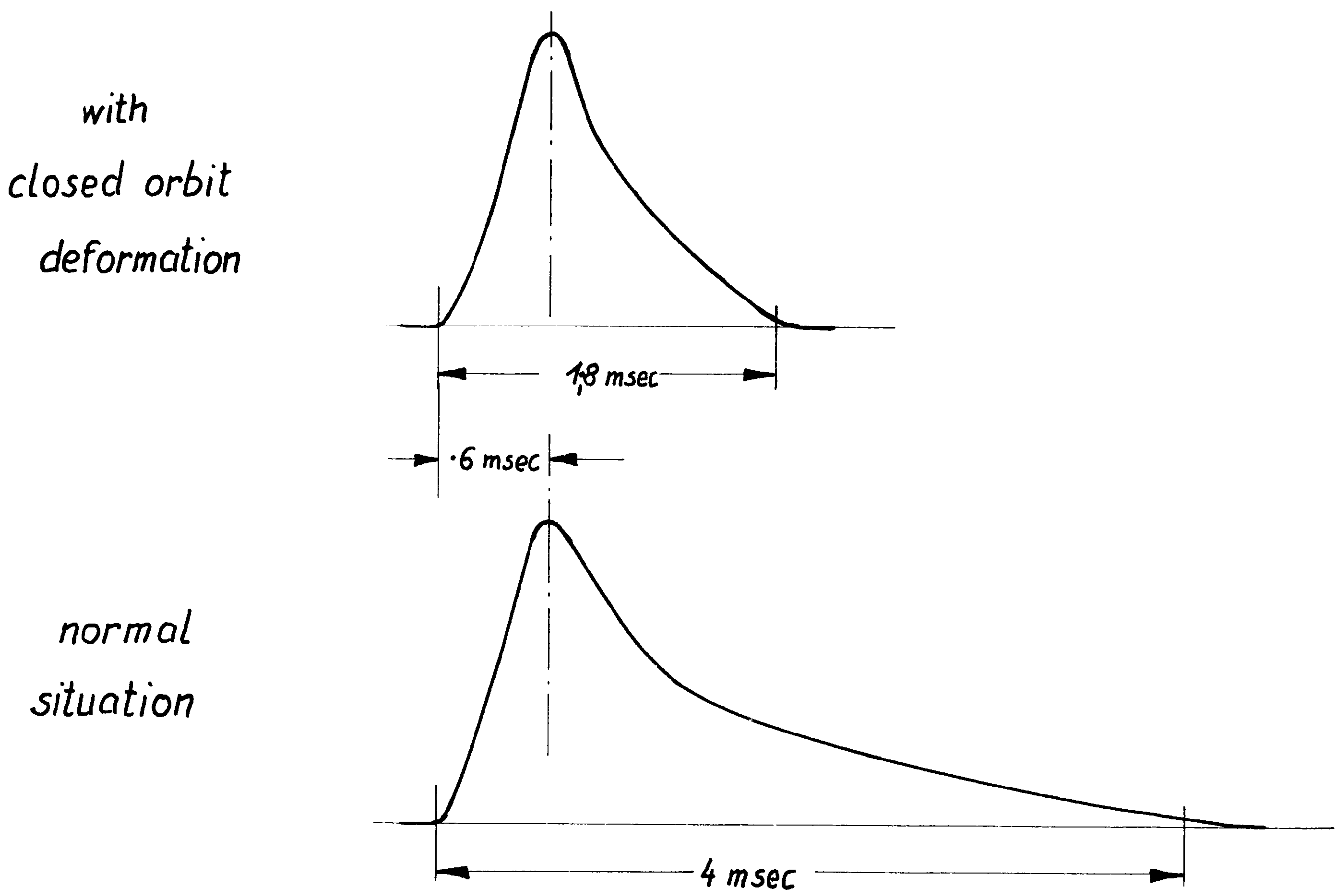
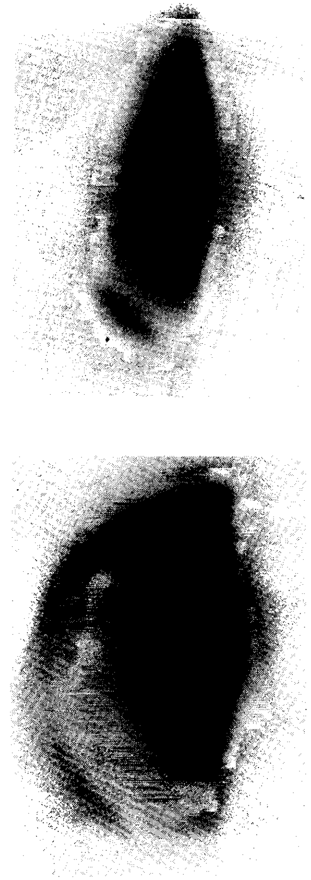


Short burst with full beam consumption produced with fast target



Radioautograph of gold foil in aluminium frame

Fig. 7 Effects of dumping