Alignment-Aspects for the HERA-Experiments ZEUS and H1

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DESY Hamburg, October 1990

1 Introduction

At the HERA accelerator two detectors, H1 and ZEUS. are installed. We, the above named, are concerned with all the survey-requirements for these detectors and together we have prepared this report.

As it would be too time consuming to give an overview about all the survey we have done and because we believe one would not gain much from a lot of general but less detailed information we have selected a few special tasks. If one would like more general information about detectors and the corresponding survey-problems we recommend that he/she should read the report of Christian Lasseur about the survey of the CERN-detectors included in this publication. The detectors at CERN and their survey-problems are similar to those at DESY.

2 ZEUS Ironyoke

2.1 Determination of reference-points at ZEUS for the final positioning of the detector relative to the beam and for the adjustment of muon-chambers

We will start with a job which we have done for the detector ZEUS. Picture No.1 shows you the two clamshells, bottom yoke, and on top of the bottom-yoke the aluminum-wheels between which the superconducting solenoid later was mounted.

On picture No.2 you can see the installation of the clamshells, on picture No.3 a cross-section of the whole detector.

Picture No.4 is a vertical cut along the beam. The weight of the detector is 3600 tons, the dimensions are: 11 x 11 x 20 meter.

2.2 The requirements for the final positioning of the ironyoke in the beam were :

a) Plane C had to be in the beamline (see picture No.5)

b) Planes A1/B1 had to be vertical and parallel to the beam

c) Plane E at the clamshell and F at the bottom-yoke should fit together because strong magnetic forces will act in these planes.(see picture No.6)

d) Between the planes A1/B1 and A2/B2 should be a gap less than or equal to 4 mm.
A gap bigger than 4 mm would strongly reduce the force of the magnetic field.

e) In order to be able to adjust the 3 parts of the yoke to the aforementioned requirements: we had to determine coordinates of the surveymarks No.1, 2, 3, 4 (see picture No.7). These points will remain visible after installation. The reference-surfaces will not be visible in the final position of the detector.

f) furthermore we had to survey cross-marks on the iron-yoke which will be used as reference for the adjustment of the muon-chambers (see picture No.7).

2.3 Measurements in order to determine coordinates of the outer survey-marks and the muon-chamber-crosses

Before we started with our measurements some preparations had to be made. Although the clamshells consist of thick ironparts with a thickness of 1 meter their endcaps were twisted because the supporting-devices did not determine a horizontal plane. By means of hydraulic jacks we corrected the torsion so that plane A1 and B1 at one clamshell and respectively A2 and B2 at the other clamshell were in in one plane.(see picture No.5 and 6) At the same time we adjusted the clamshells so that the surfaces A1/B1 and A2/B2 were in a vertical plane and the planes C at both clamshells were horizontal. This was done because it makes following measurements much more convenient.

The points were determined by three-dimensional foreward- intersections. During this procedure it was necessary to check several times whether the clamshells had sunk or become twisted again, due to bending of the floor or movements within the hydraulic jacks. The survey of the points was very difficult due to the following constraints:

a) Around the clamshells and between them there was not much space. Therefore the tripods had to be situated near by the clamshells. For that reason the lines of sight were extremely steep, thus the muon-chamber-crosses in the upper region of the clamshells were very badly aimed at which reduced the accuracy of these points especially in height.

b) The lines of sight to some crosses were covered so that excentric targets had to be observed. In order to reach these crosses and to hold an excentric target against them one could use a special basket which is lifted by the crane of the hall. But due to the shape of the clamshells all those crosses which were below the roof of the clamshell were not reachable by the crane and using ladders for heights up to 10 meter is too dangerous.

c) The disadvantageous shape of the clamshells and the fact that the bottom-yoke covered the space between the shells made it necessary to use a lot of standpoints and led to forward intersections which sometimes were far away from ideal geometric conditions.

The accuracy of our measurements was such that the position of the 100 muon-chamber-crosses in space was determined with a standard- deviation of ±0.3 up to ±0.6 mm. The biggest contribution to this value came from the error in the determination of the Z-coordinates (height) of the high situated crosses, whilst the value for X-coordinates as well as Z-coordinates was ± 0.1 mm. The accuracy of the surveymarks No 1-4 was ±0.3 mm.

2.4 Calculation of the coordinates

The measurements could only be done, when the clamshells were not closed, therefore the calculations of the coordinates had to be carried out separately for each clamshell and related to coordinate-systems which were referenced to the surfaces of each clamshell as you can see in picture No.8.

Later on the clamshells have to be aligned, so that they hare the correct relationship to each other. They must also be in the correct position relative to the solenoid and the beam. For this one needs reference-points at both clamshells which have coordinates in one single coordinate-system.

This means:

Although we were forced to calculate at first for each clamshell in separate coordinate-systems we had to take into account that later on these systems have to coincide with each other and with the system which is related to the solenoid.

If the shape and the dimensions of the clamshells had not deviated from the stated drawing dimensions it would have been easy to fulfill the above described requirements.

However during the production and assembly of such large iron- parts deviations are unavoid-able. Our measurements show deviations at the mating-surfaces from ±0.2 up to ±1 mm and at the inner walls of the endcaps up to 8 mm.

For this reason we had to shift rotate, compress or stretch the coordinates until the real measured shape of the clamshell was optimally fitted to the designed theoretical model.

Two examples should show you the consequences if this procedure would have failed:

1. Example:

Suppose the zero-point of the z-axis of one clamshell had been calculated wrong. so that it is by the amount h too high with respect to the clamshell. (see picture No.10)

The result would be that during the height-adjustment the surface E1 slides down at the surface F1 of the bottom- yoke. This affects a movement in X by the amount d, so that the gap becomes too big and the magnetic field will be reduced.(see picture No.9)

In addition the axis of the solenoid will be higher than the window of the right clamshell, which causes mechanical problems with other installations.

2. Example:

Let‘s suppose that the position of the coordinate-system is wrong in an other way.

Due to inaccurate surfaces A1 B1 (in the picture no 11a drawn exaggerated) the lateral offset of the y-axis from the surfaces A1 and B1 would be too big and the X- as well as the Z-axis would be rotated by the angle alpha against plane C.

Due to an interference of the yokes as you can see in picture No.12 we would not be able to adjust the clamshells such that the coordinate-axes coincide. The shells would remain in a position similar to that in picture 13, where the surfaces A1,B1,A2 and B2 were touching each other.

When the field is switched on strong magnetic forces would pull the yokes against each other and would deform the clamshells and damage them.

2.5 Results of our measurements and calculations

Until now the 3 yokes were not moved into the beam-position, but the two clamshells were adjusted with respect to the bottom-yoke and relative to each other in order to check if they fit together when the magnetic field is switched on.

At first we moved the clamshells on their rails until a lateral offset of about 50 mm from the bottom-yoke was left on both sides. This was necessary on the one hand in order to get a gap through which the bottom-yoke remained visible and on the other hand to avoid that the clamshells touching the bottom- yoke during the height-adjustment.

We waited one night, meanwhile the floor of the hall sank down by the heavy load of the 3 yokes. Then we observed the bottom-yoke in order to check whether it was still horizontal. Afterwards we adjusted the clamshells with respect to the bottom-yoke in height. Then the clamshells were moved on their rails until they touched the bottom-yoke. At that time we realized that the gap between the clamshells was not 4 mm but about 7 mm. This was not caused by mistakes in our survey or calculations but by a mistake in the design of the bottom-yoke. This yoke was made too wide.

As it is absolutely necessary to have a gap not bigger than 4 mm, we had to adjust the clamshells about 4 mm higher than planned. We hope that this will not cause big mechanical problems for the following installations in the future because the amount of 4 mn is comparatively small.

3 Targets and Devices for Length-Measurements

In the following section we will describe special targets and devices for length-measurements which we have developed already in 1977 for the survey of the MARK-J-detector at the accelerator PETRA. We are still using them because they have been tried and tested before and they are easy to make in different sizes.

If one wants to measure angles or distances to reference-points at a detector normally one can not use common targets like Taylor-Hobson-spheres or reflectors or a base rod and the corresponding sockets. because

a) they are too big for the limited space
b) spheres and similar targets are not visible from every direction, for example not from below.

Therefore we developed three types of targets as you can see on picture No.14. At the detector one does not need a bracket or a socket in order to support the targets but only a hole in order to plug them in.

These targets are designed such that the first two both have their sighting points on the central axis and at the same distance d from the reference flange. The sighting-point consists of a hole with a diameter of 0.4 mm which is very accurate to observe if the distance between the telescope and the target is of the order of magnitude up to 20 meter. The third target which is used for length-measurements has a measuring edge in the plane of the central- axis and also at the same distance d from the reference flange. All three targets define the same point in space. On picture No.15 target-type No.1 could be seen from stand 1 and 3.

If necessary one can rotate the target so that the hole is visible from each side. If one is looking from stand 3 to point B type No.11 will be useful.

If one wants to combine angle- and length-measurements from one stand to a reference-point (for example from stand No.2 to point C) one can use type No.I and II for the angle-measurement and type No.III together with a special length-measuring-device for the length-measurement.

Usually we prefer three-dimensional foreward-intersections for point determinations. but sometimes there is not enough space available so that one is forced to measure one angle and one distance. For the distance-measurements we had to develop a special device because until today no electro-optical length-measuring-device is available which could be force-centered, did neither require a track for guiding the reflector nor an large reflector and a corresponding socket and which is able to measure distances up to 10 meter with an accuracy of ±0.1 mm.

On picture No.15 one can see that our length-measuring-device is centered by means of a ball and a funnel-shaped device with respect to the centre of the tripod. At the other end there is a dial gage.

During length-measurement the edges of the pointer of the dial gape and the target have to be rectangular to each other. In between there is a stick-micrometer which can he extended up to 9.5 meter.

4 Adjustment of the Endcaps of the H1-Magnet

How we want to describe one task which had to be done during the assembly of the clamshells of the other detector H1.

Picture No.16 shows an overview of the iron-yokes of the detector H1. At first the inner iron-plates of the 4 endcaps had to be errected. On picture No.17 one can see in the foreground one plate resting on a stool and being connected with an assembly-device which looks like a scaffold.

The purpose of the assembly-device is firstly to prevent the ironplates from falling down. secondly to adjust them.

4.1 The requirements for positioning of the first plate were the following. (Additionally look at picture No.18)

a) The axis AA, determined by the centre of the cylindrical holes had to be in the same height as the beam and parallel to it.

b) The surface of the plate had to be rectangular to the inclined beam. That means, tilted with respect to a vertical plane by 5.9 mrad

c) The plates of the four endcaps had to be plane parallel

d) The lateral offset d from the interaction-point had to be according to the designed value

We will confine this report to the explanation of how we accomplished requirements b), c) and d).

4.2 Measurements

As the rotation of the theodolite axis is in both the horizontal and vertical planes, it is easy to adjust an object in these planes using a straight-forward approach. However if the object lays on an inclined plane then another, more indirect approach is usually necessary.

An example of a common indirect approach is as follows; One can survey at least three points according to a common method (for example three-dimensional-forward-intersections). After that one has to calculate coordinates of the points and calculate whether they are situated within a plane with the required position in space. Then one has to make a further measurement in order to move the determined points by calculated amounts so that they meet the theoretical position of the plane.

For that it is necessary:

a) To have well defined targets in 3 dimensions. Surfaces would not be sufficient.

b) To make several steps of measurements and calculations

c) To have enough space in order to measure forward-intersections

d) To have enough time.

But this is a very time cosuming and inconvenient way. Therefore we adopted the following method:

In the picture No.19 one can see the assembly-device with the adjustment-bolts and steel-rules. On the floor we had a scratch, which was rectangular to the beam and we knew its lateral offset from the interaction-point.

We centered the theodolite over point A and used it as a level in order to determine the vertical offset HA of the optical axis from the interaction-point.

Then we brought the telescope in a position which was rectangular to the scratch (if one looks from above) and inclined by the angle alpha equal to 5.9 mrad. We put a prism on the telescope which is rotatable around the optical axis. (See picture No.20)

If one rotates the prism, the optical axis determines a plane in space which will be planparallel to the desired position of the iron plate.

The offset a between the two planes (see picture No.19) could be calculated and the adjustement-bolts were screwed until we read this offset by means of the telescope at the steel-rule.

Now the first iron-plate could be assembled to the assembly-device in the required position.

5 Survey the shape and determine the axis of cylindrical vessels

On picture No.21 one can see the endflange of a vessel. We determined the centre Z1 of this flange by using large beam compasses. After having transfered the theoretical radius of the flanges into the needles of the compasses we created four arcs with respect to the inner rim of the flange. The arcs were marked on a previously installed transparent plate. The same was done at the second flange of the vessel.

From the picture which was shown by the arcs we could make a conclusion about the shape and dimensions of the flange. (See picture No.22) Then we had to find an averaged position between the arcs which represents the centres Z1 and Z2 of the flanges. Afterwards we pointed the theodolite in the axis. (see picture No.23 and 24)

In order to check whether one flange is perpendicular to the axis Z1-Z2 within the horizontal plane a second theodolite was positioned at one side of the vessel and its line of sight had to be brought parallel to the flange. We solved this problem by holding rules to the flange and by making readings with the theodolite. The line of sight and the middle-axis of the vessel should then have included an angle of 90 degrees, which could be derived from the angles alpha and beta and the fact that the sum of angles in the triangle has to be 180 degrees.

The perpendicularity between the flange and the axis Z1-Z2 in the vertical plane was determined in such a way that the tilt of the axis had been compared with the corresponding readings at the rules.

By the way we will return to the beam-compasses and describe a further possibility to use them. Some pears ago when the HERA-tunnel was built we had to check whether the axis of the tunnel was in the correct position. Therefore in equal distances of 10 meter the circular profile of the tunnel should be measured and in addition the centre of these profiles had to be determined in order to check how much it deviated from the theoretical axis of the tunnel. (See picture No.25)

One could solve this problem by determining coordinates of some points along the circumference of each profile and calculating the shape and the centre of the profile. But this would be a time consuming way and would be difficult due to a lot of reasons but especially since it would not be easy to reach the points at the tunnel-wall in order to hold a target against the wall or mark a cross at the wall. The diameter of the tunnel-cross-section is 5.2 meter and it is not easy to keep a ladder at the curved wall.

There are devices available which are able to measure irregular tunnel-profiles but they are expensive and time consuming in usage.

To solve the problem with beam-compasses is a very fast and cheap method.

We determined the centre and the shape of the tunnel-profile in the same way as described for the cylindrical vessel. We put a tripod with a mounted aluminum-plate on the floor of the tunnel so that the surface of the plate was situated within the profile which had to be measured. (See picture No.26). We marked the arcs on the plate and found the centre between these arcs. Then we determined the centre- point by angle- and length measurements with respect to known reference-points.

6 Figure captions

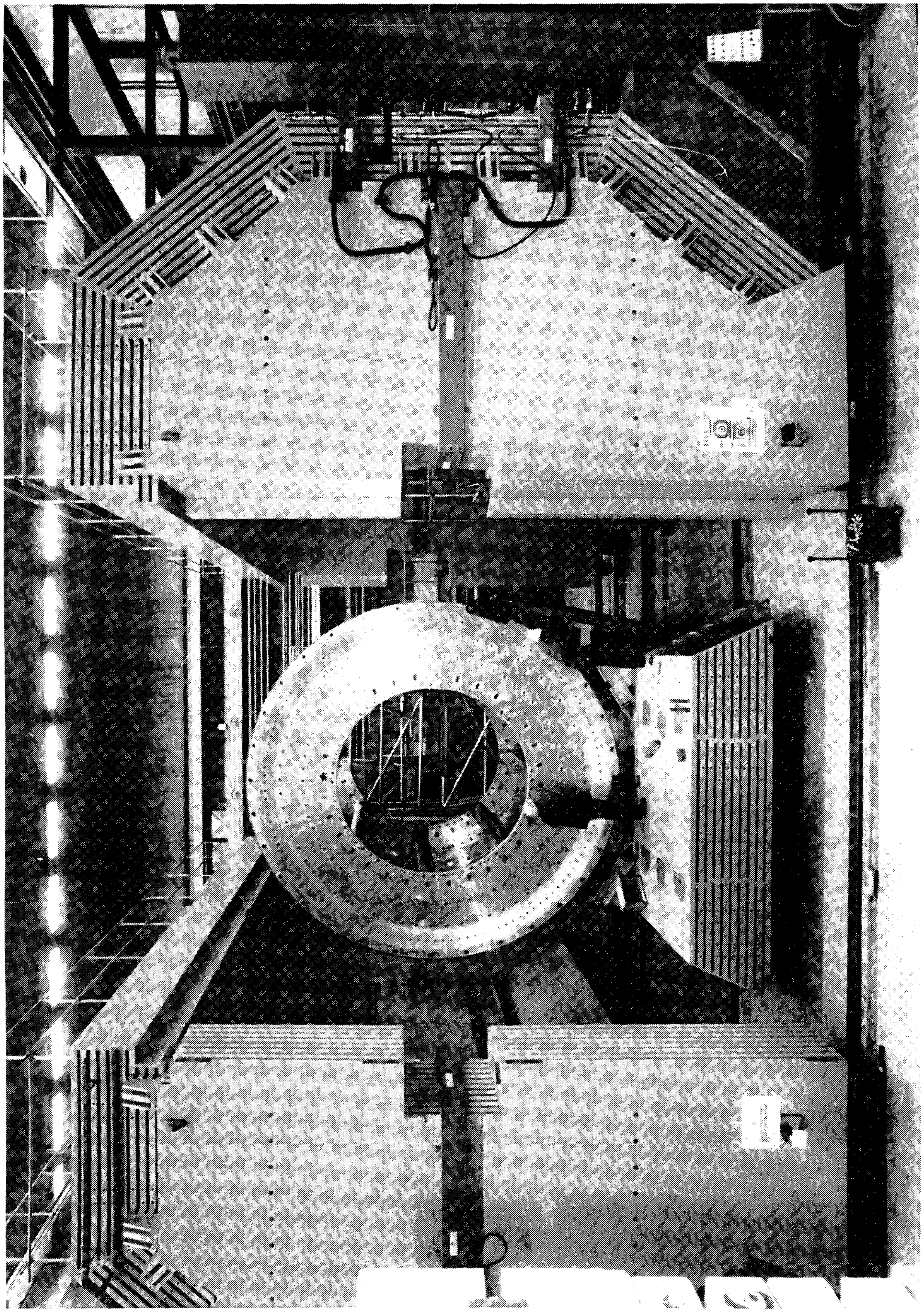


Fig. 1: Clamshells, Bottom Yoke and Aluminiumwheels (Exp. ZEUS)

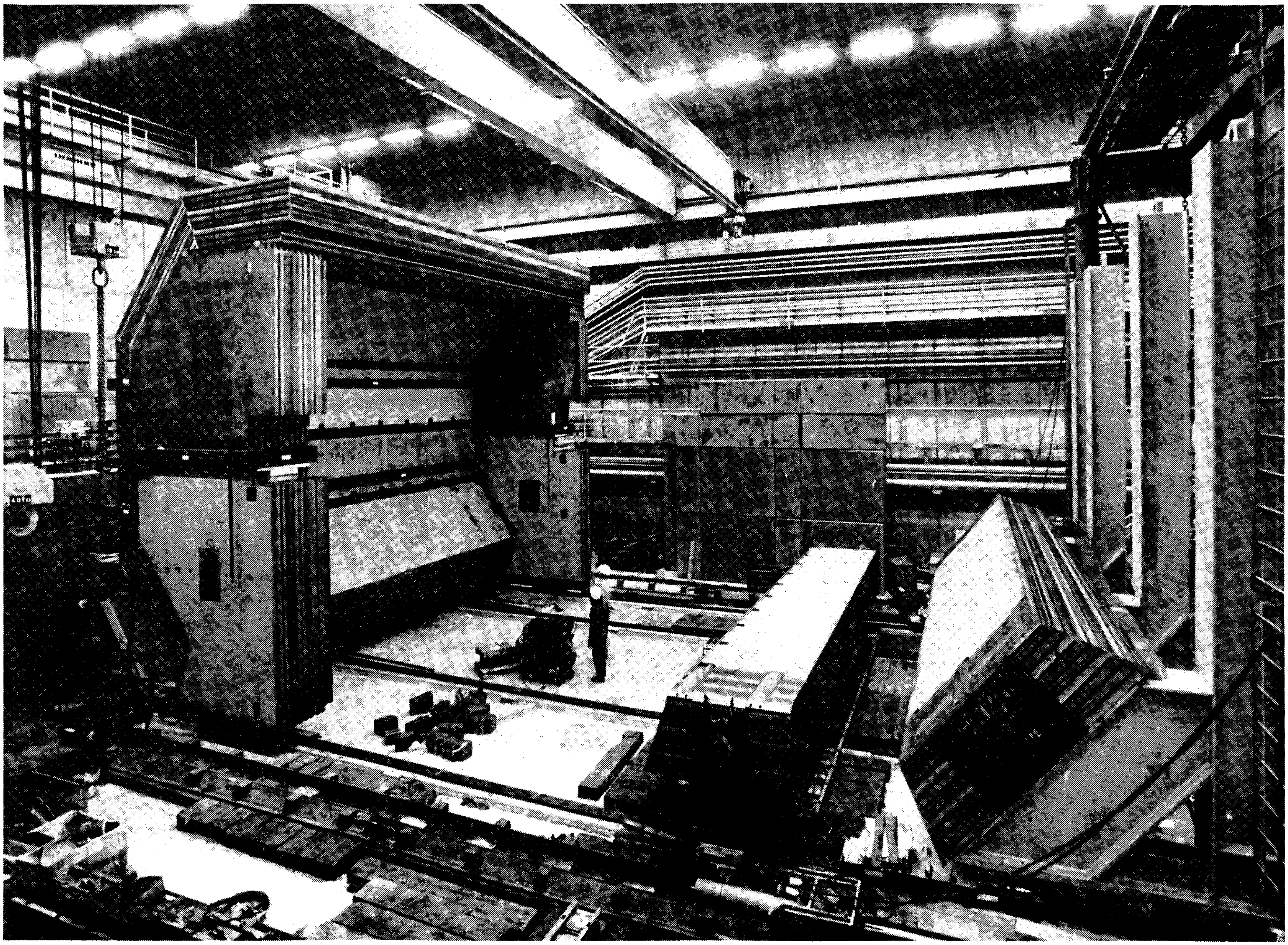


Fig. 2: Installation of the Clamshells at ZEUS

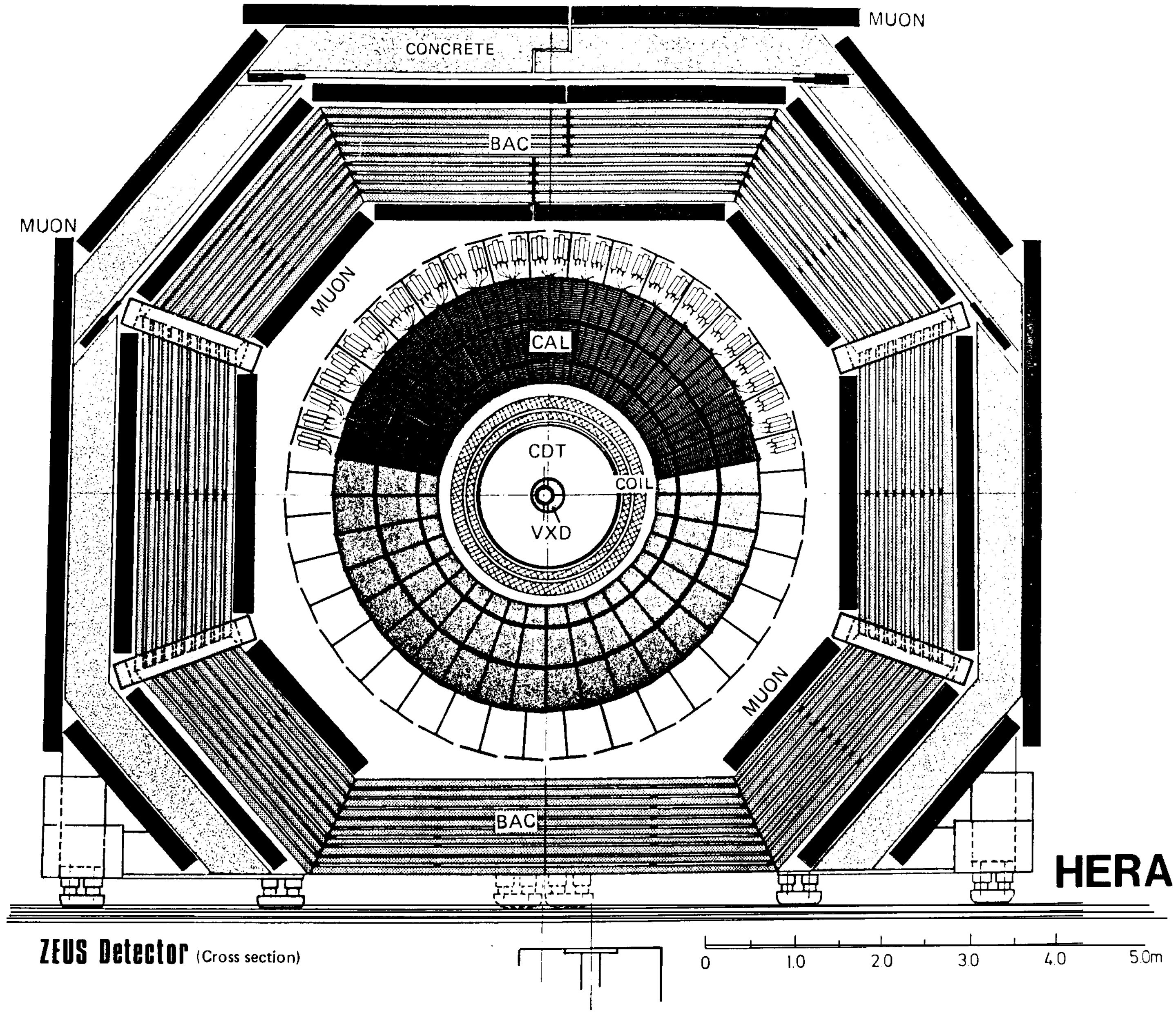


Fig. 3: Cross–section of Experiment ZEUS

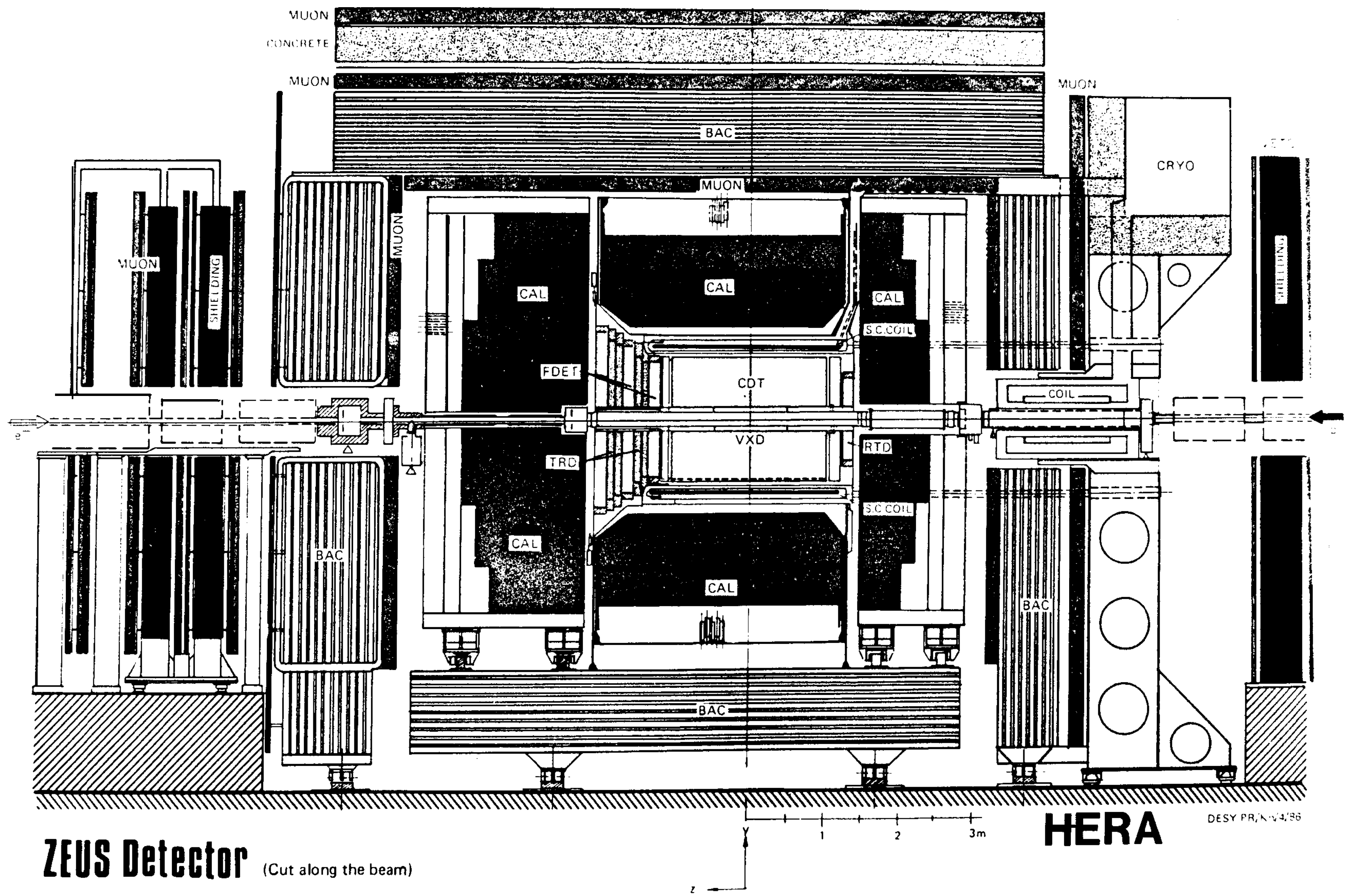


Fig. 4: Vertical cut along the beam of Experiment ZEUS

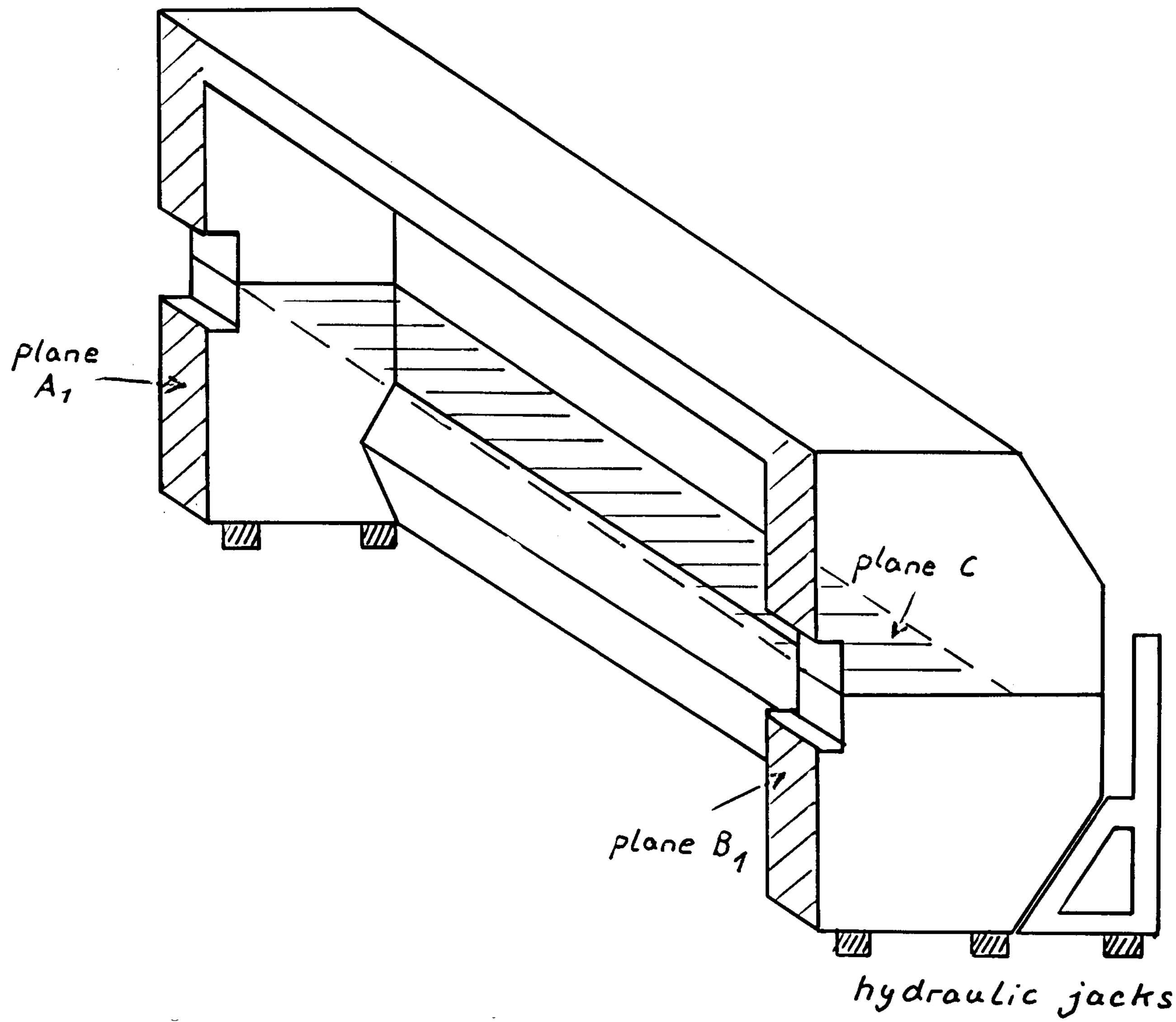


Fig. 5: Clamshell at ZEUS

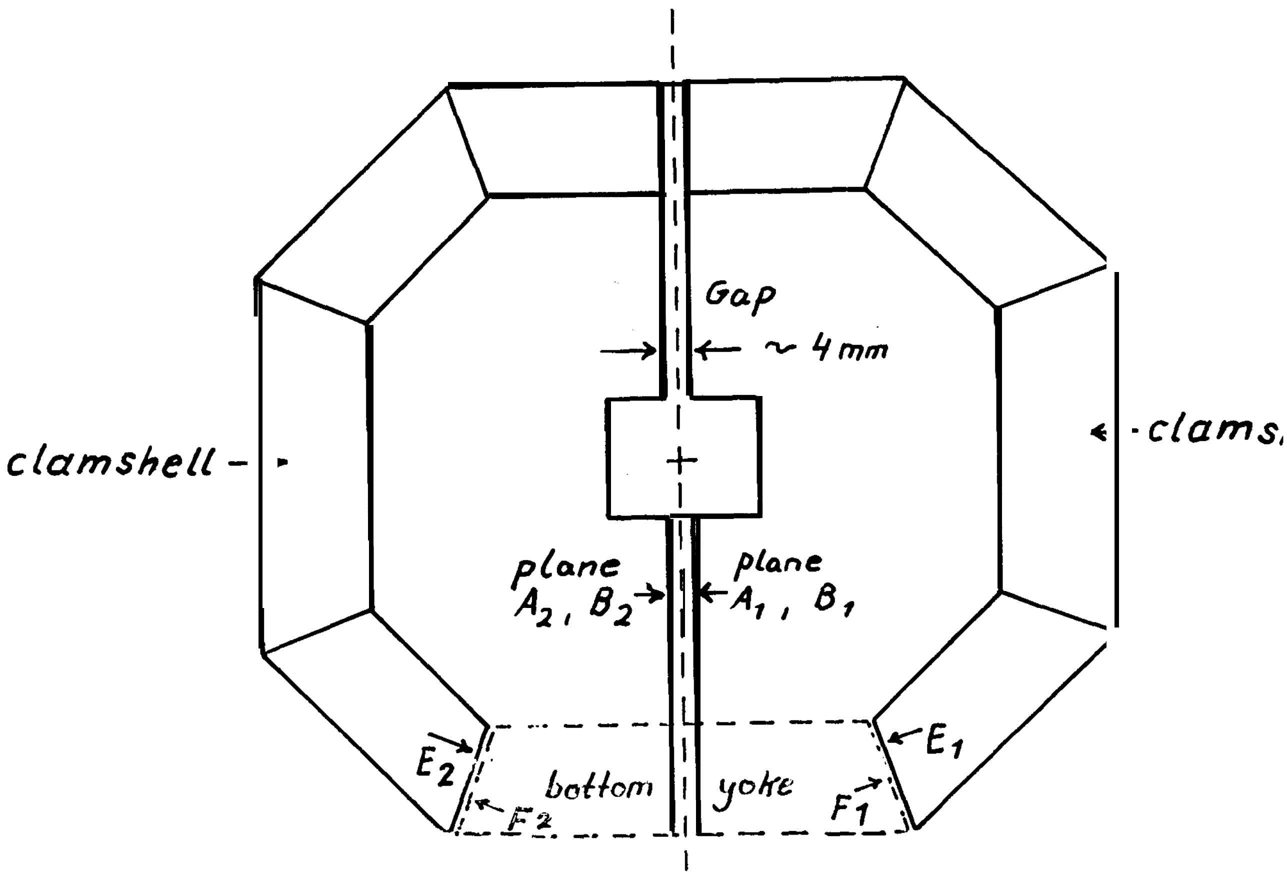


Fig. 6: Clamshells and Bottom Yoke (to shove the requirements at mounting)

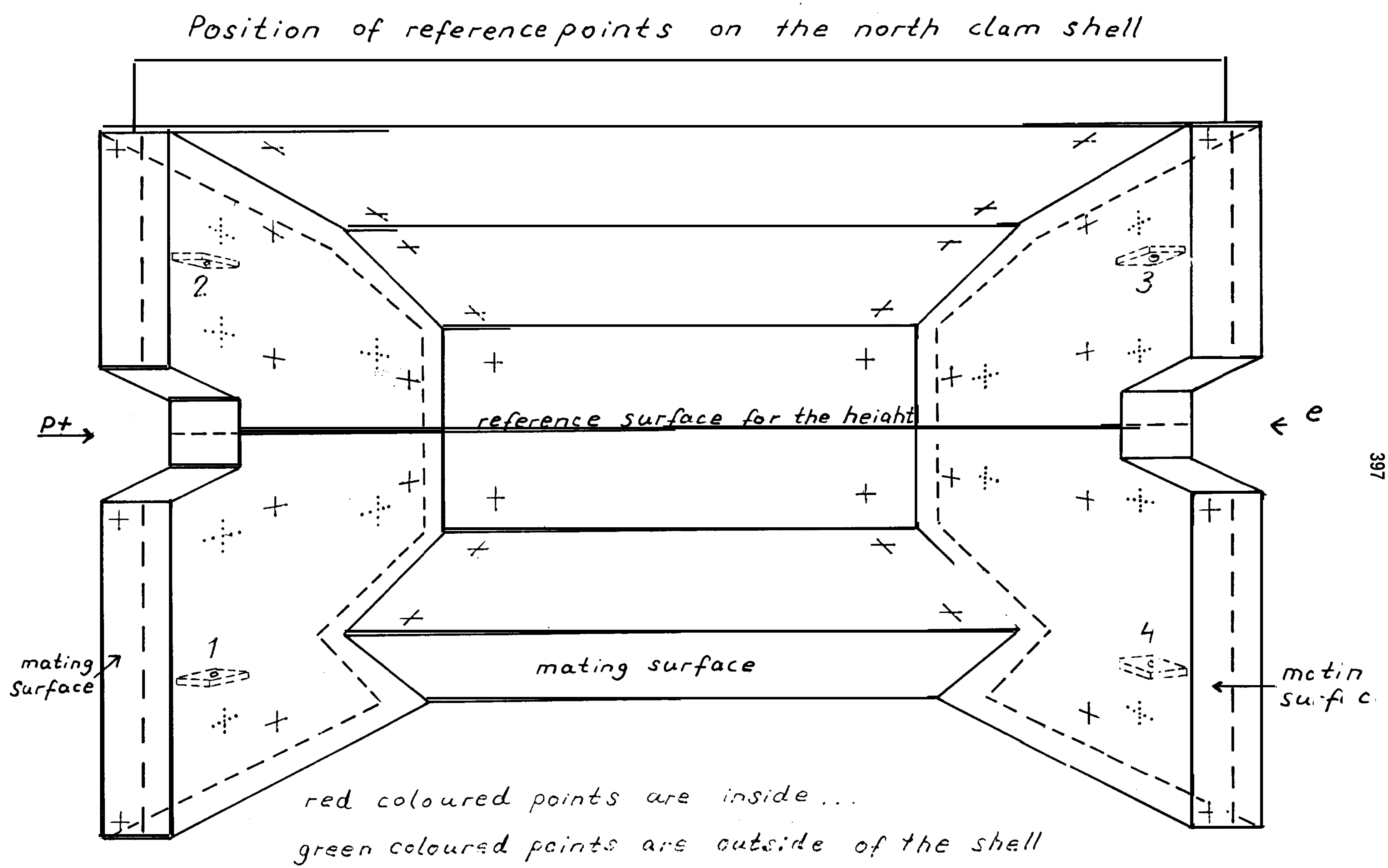


Fig. 7: Position of Referencepoints on the North Clamshell (ZEUS)

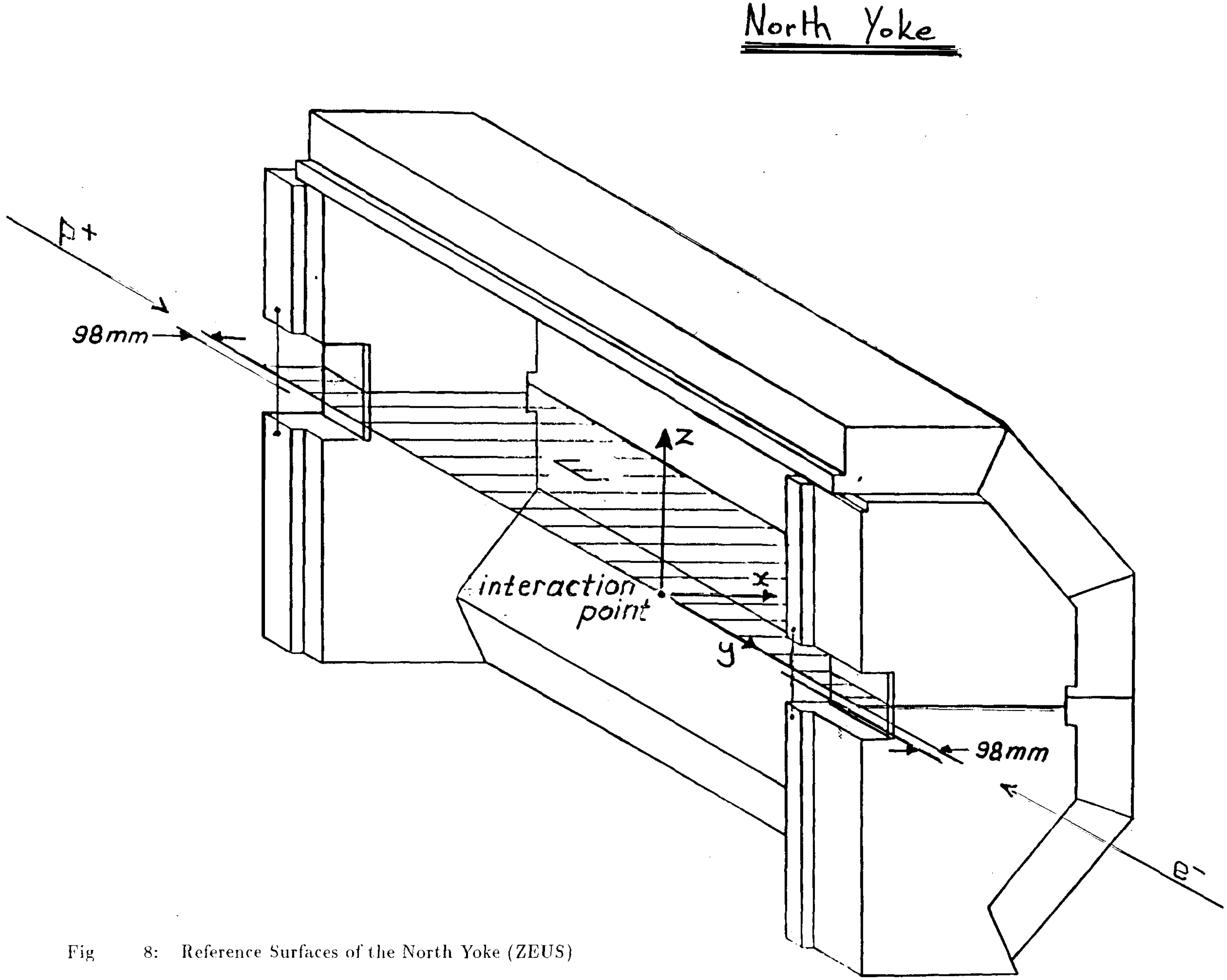


Fig 8: Reference Surfaces of the North Yoke (ZEUS)

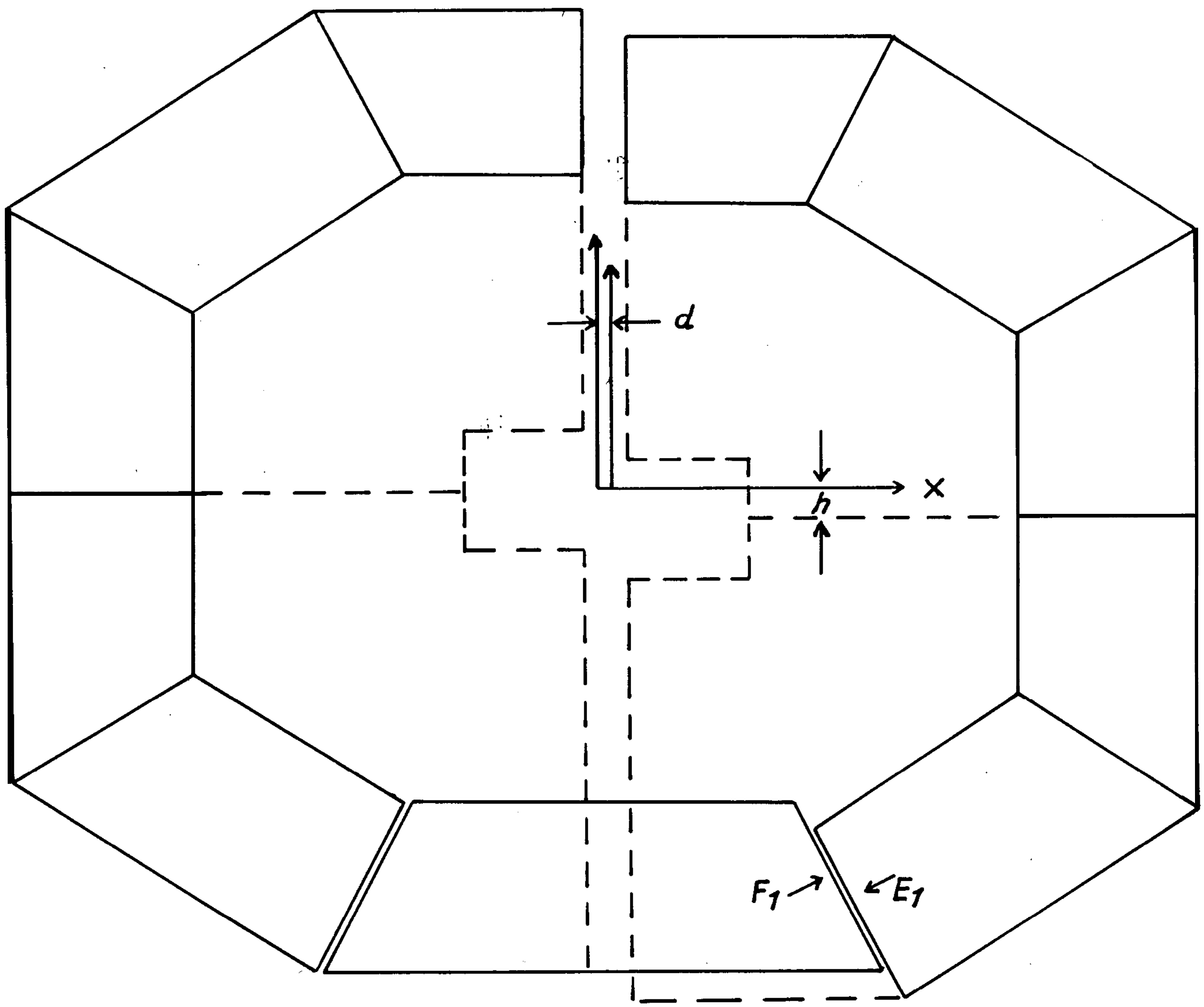


Fig. 9: Situation if Adjustment of Yokes is wrong

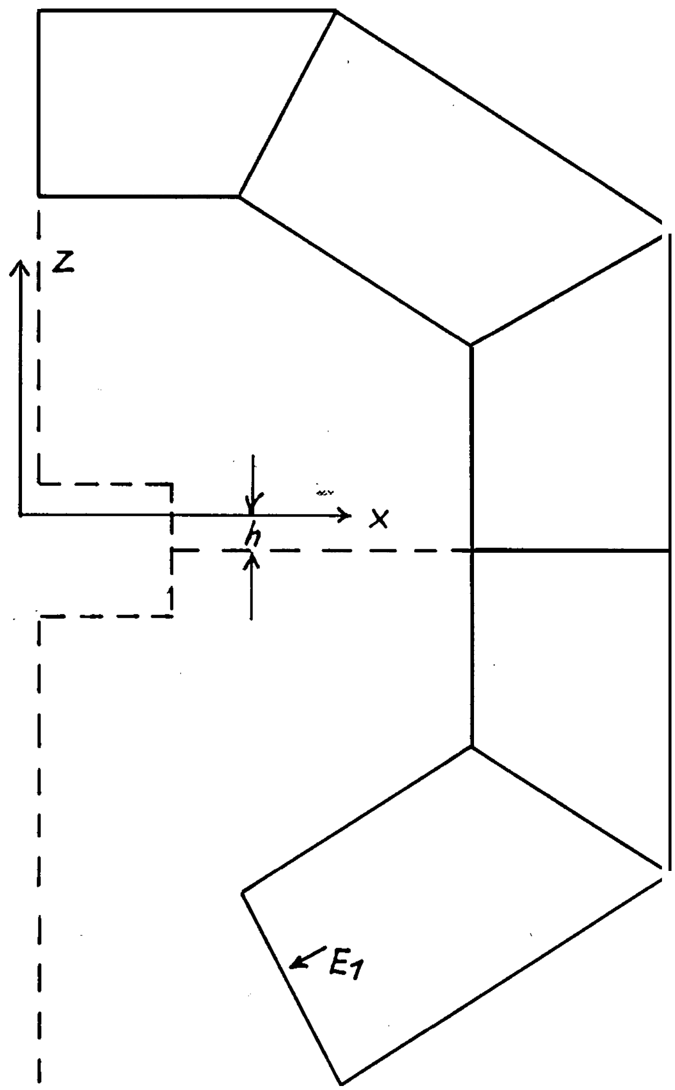


Fig. 10: Wrongly-calculated Clamshell in z (ZEUS)

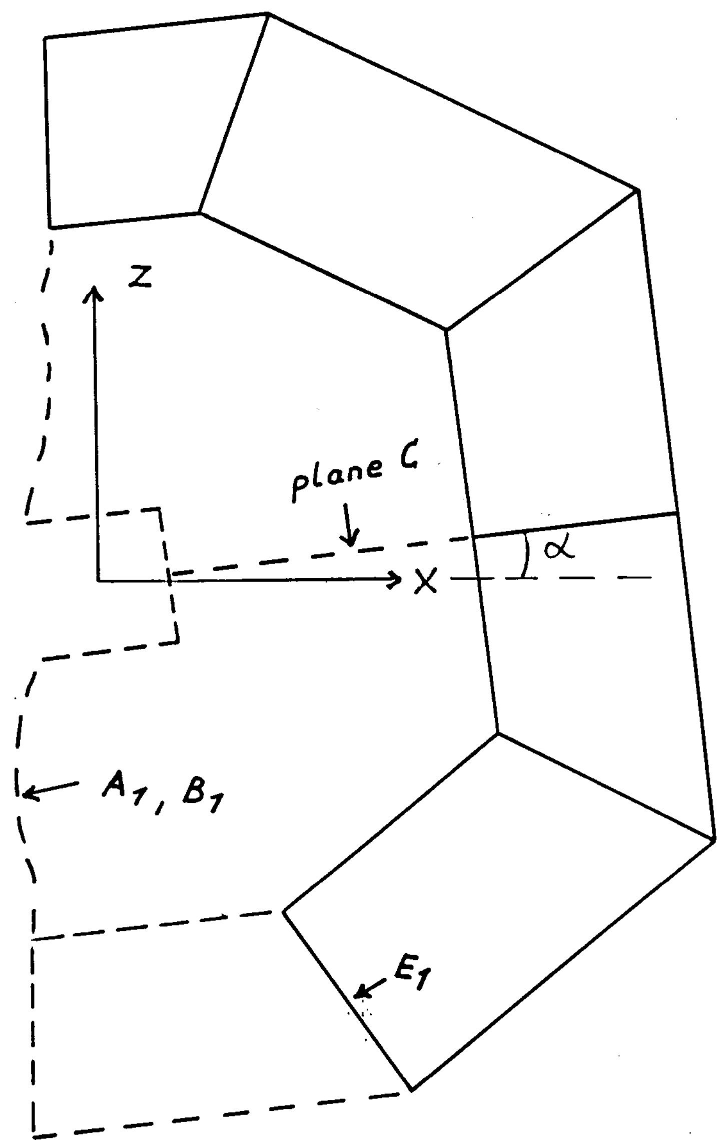


Fig. 11: Inaccurate Surfaces at one Clamshell (ZEUS)

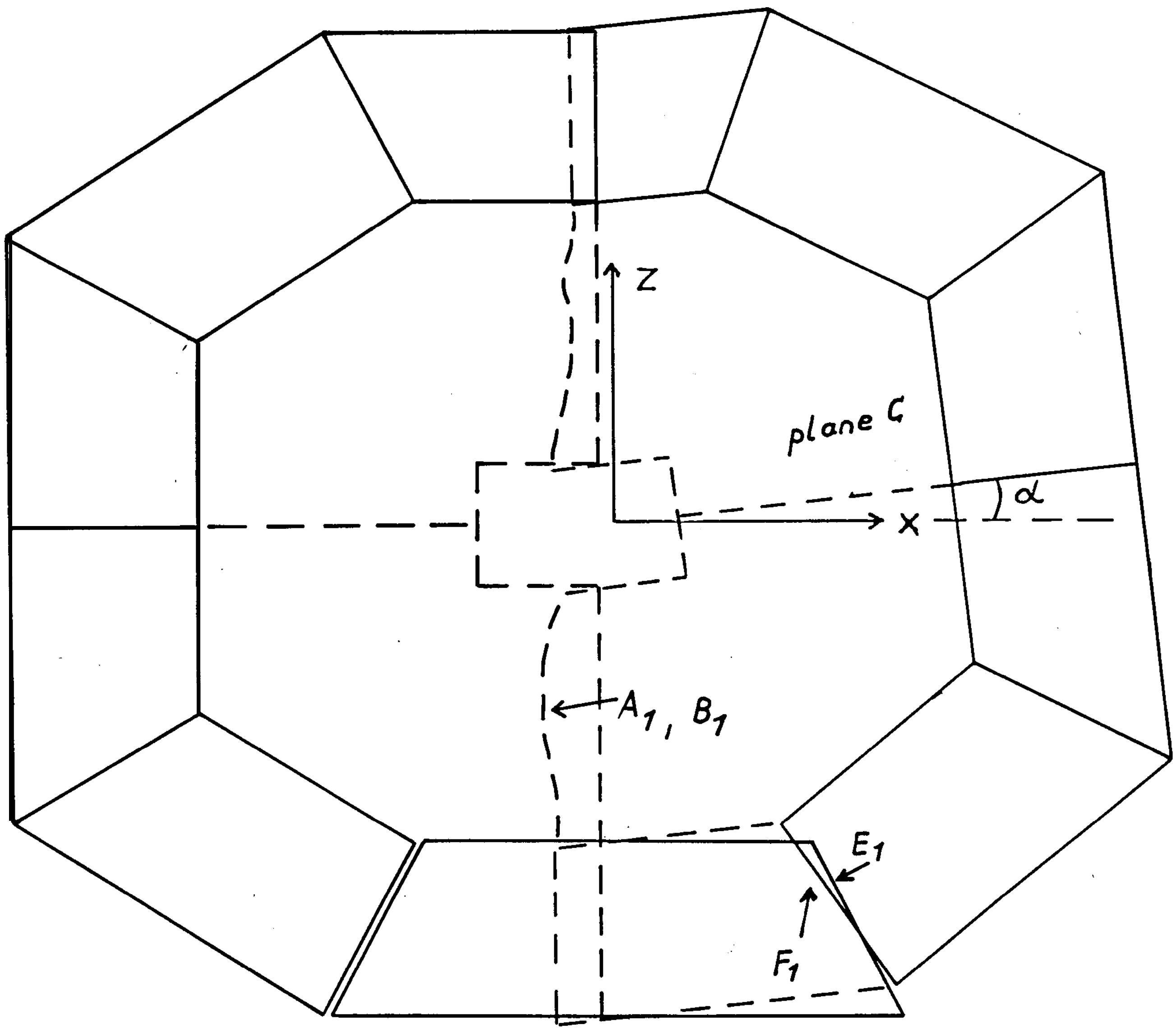


Fig. 12: Interferences of the Yokes at ZEUS

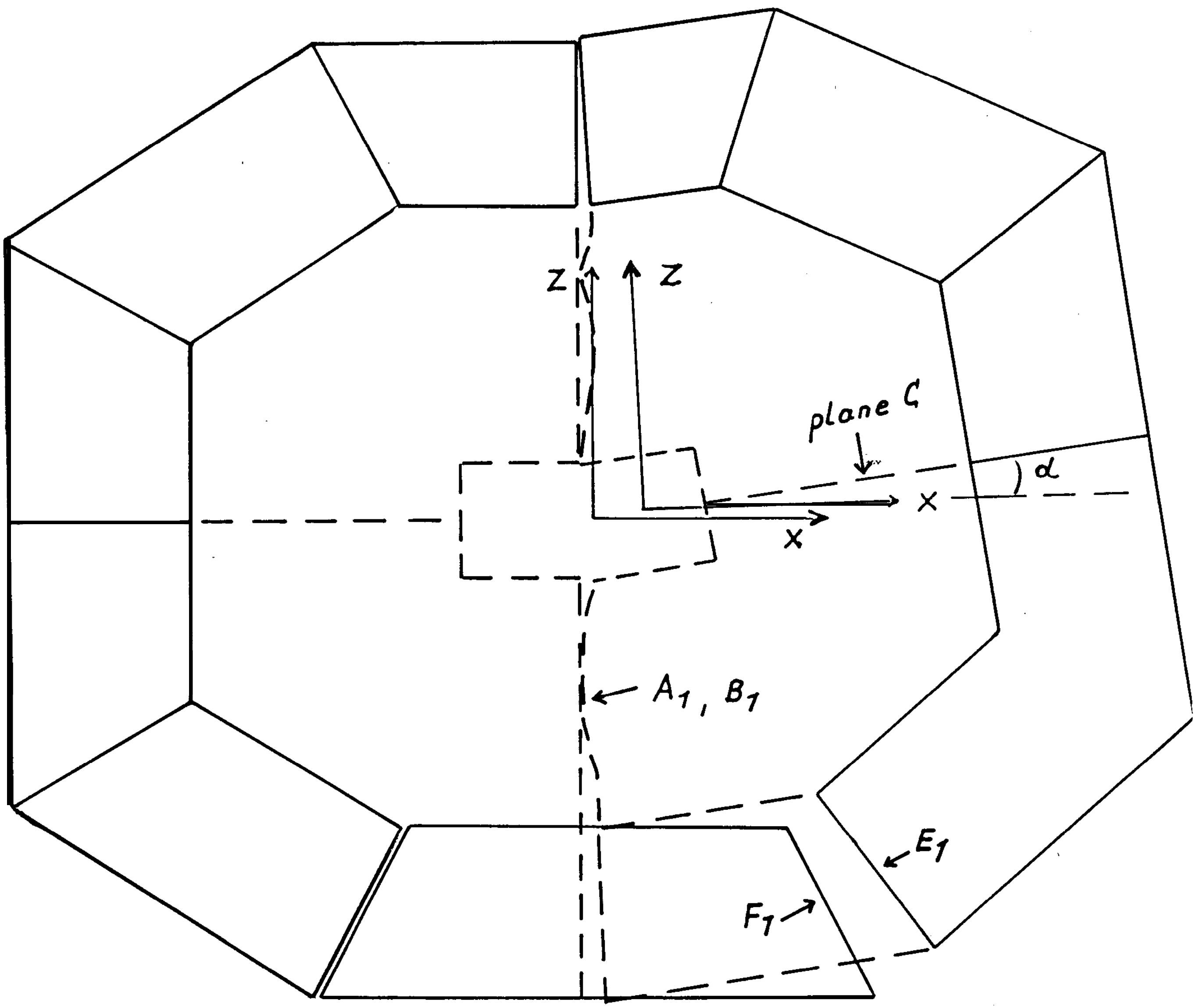


Fig. 13: Interferences of the Yokes at ZEUS

Different types of Survey - Targets
with the Referencepoints in the same Position

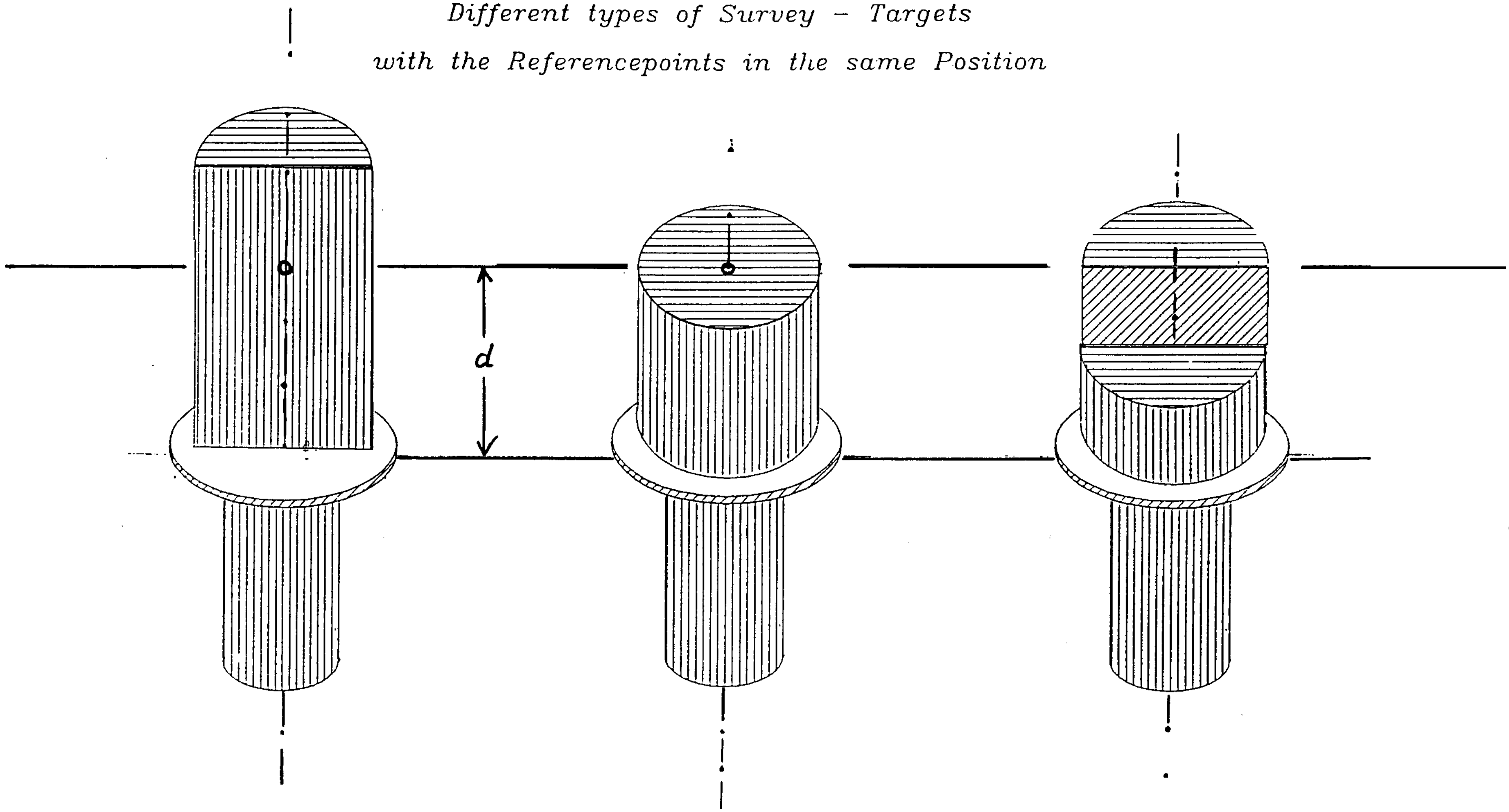


Fig. 14

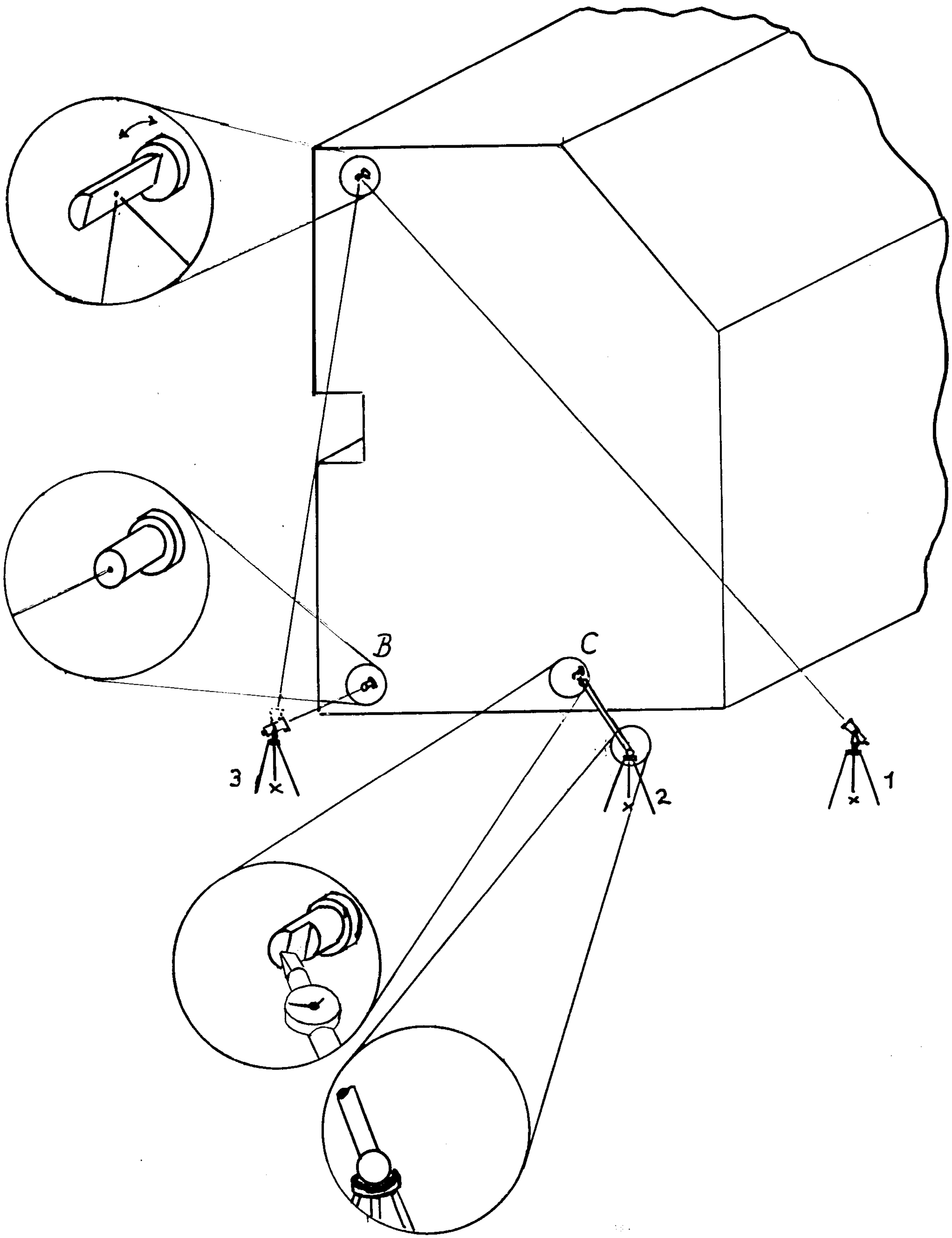


Fig. 15: Application of Targets

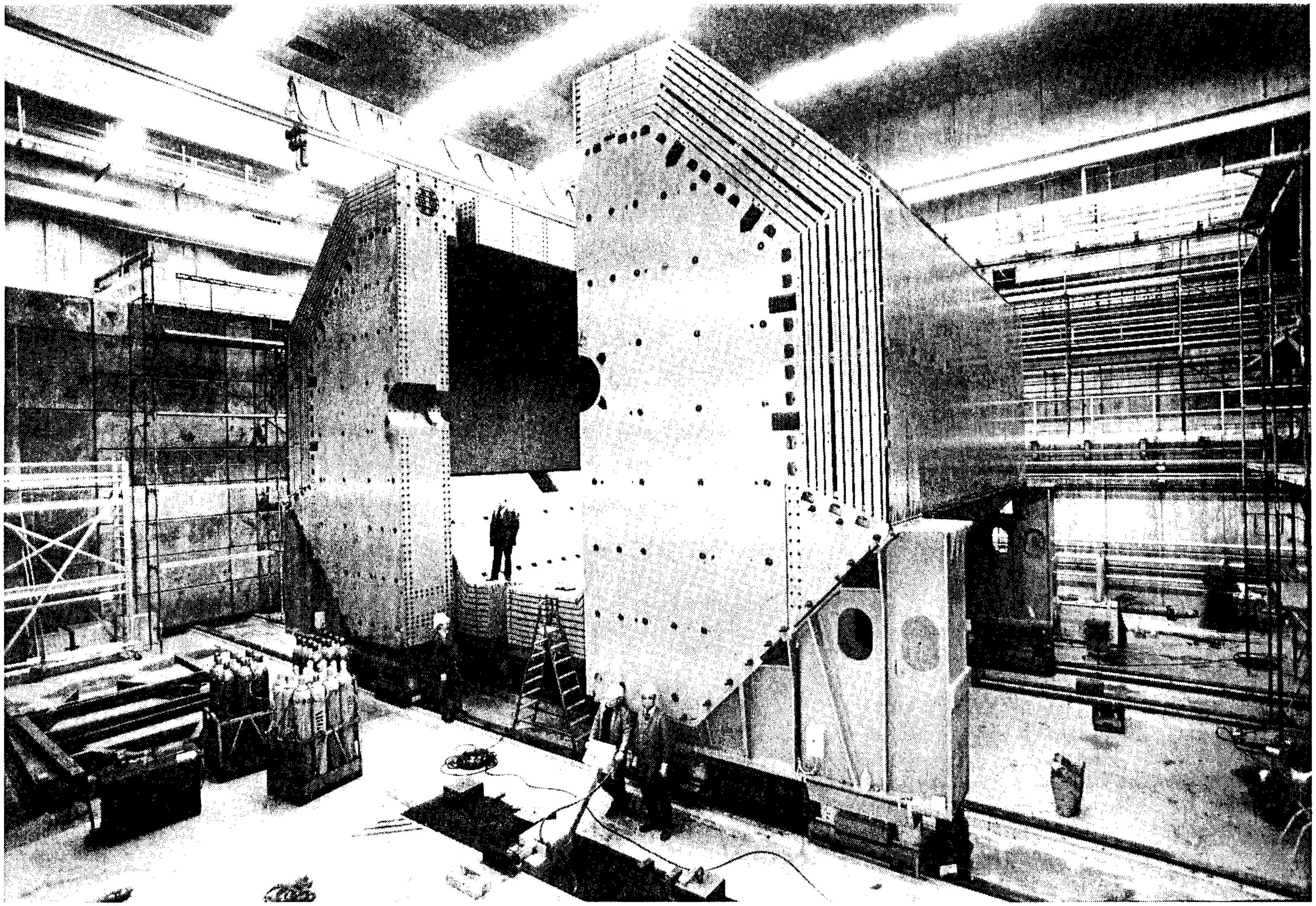


Fig. 16: Overwiev of the Iron Yokes at Ex H1

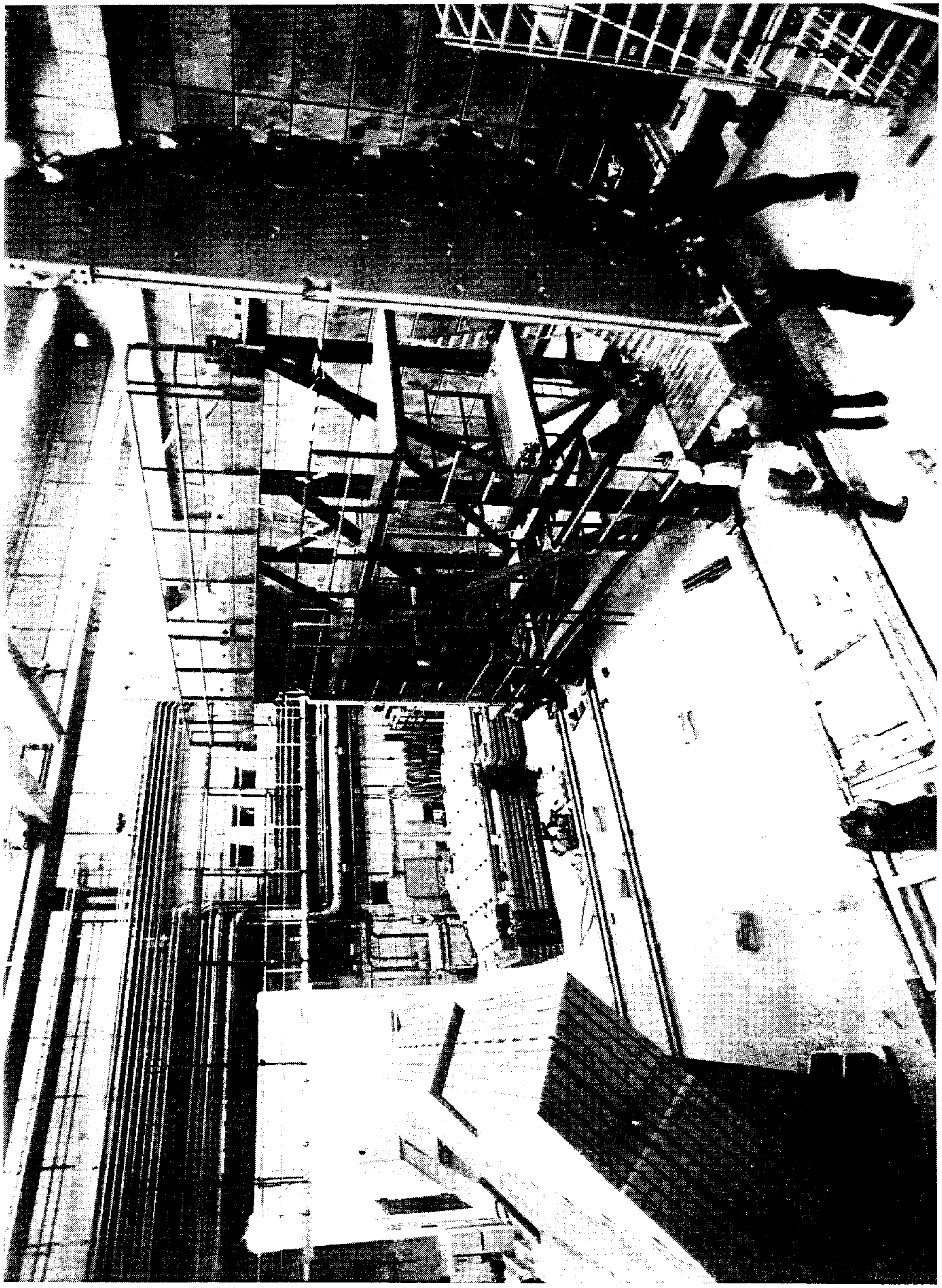


Fig. 17: Mounting of Endcaps (H1)

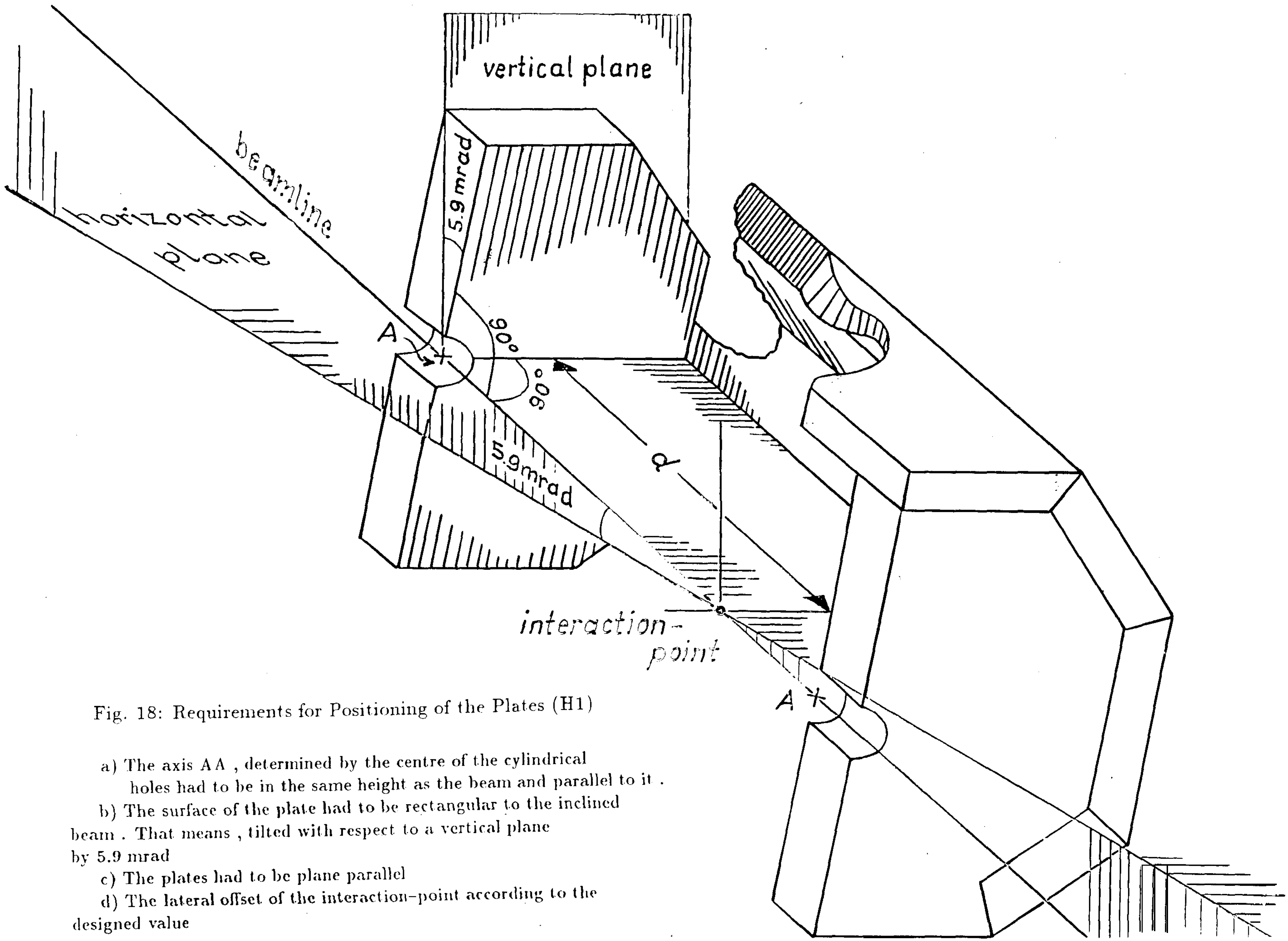


Fig. 18: Requirements for Positioning of the Plates (H1)

a) The axis AA , determined by the centre of the cylindrical holes had to be in the same height as the beam and parallel to it .

b) The surface of the plate had to be rectangular to the inclined beam . That means , tilted with respect to a vertical plane by 5.9 mrad

c) The plates had to be plane parallel

d) The lateral offset of the interaction-point according to the designed value

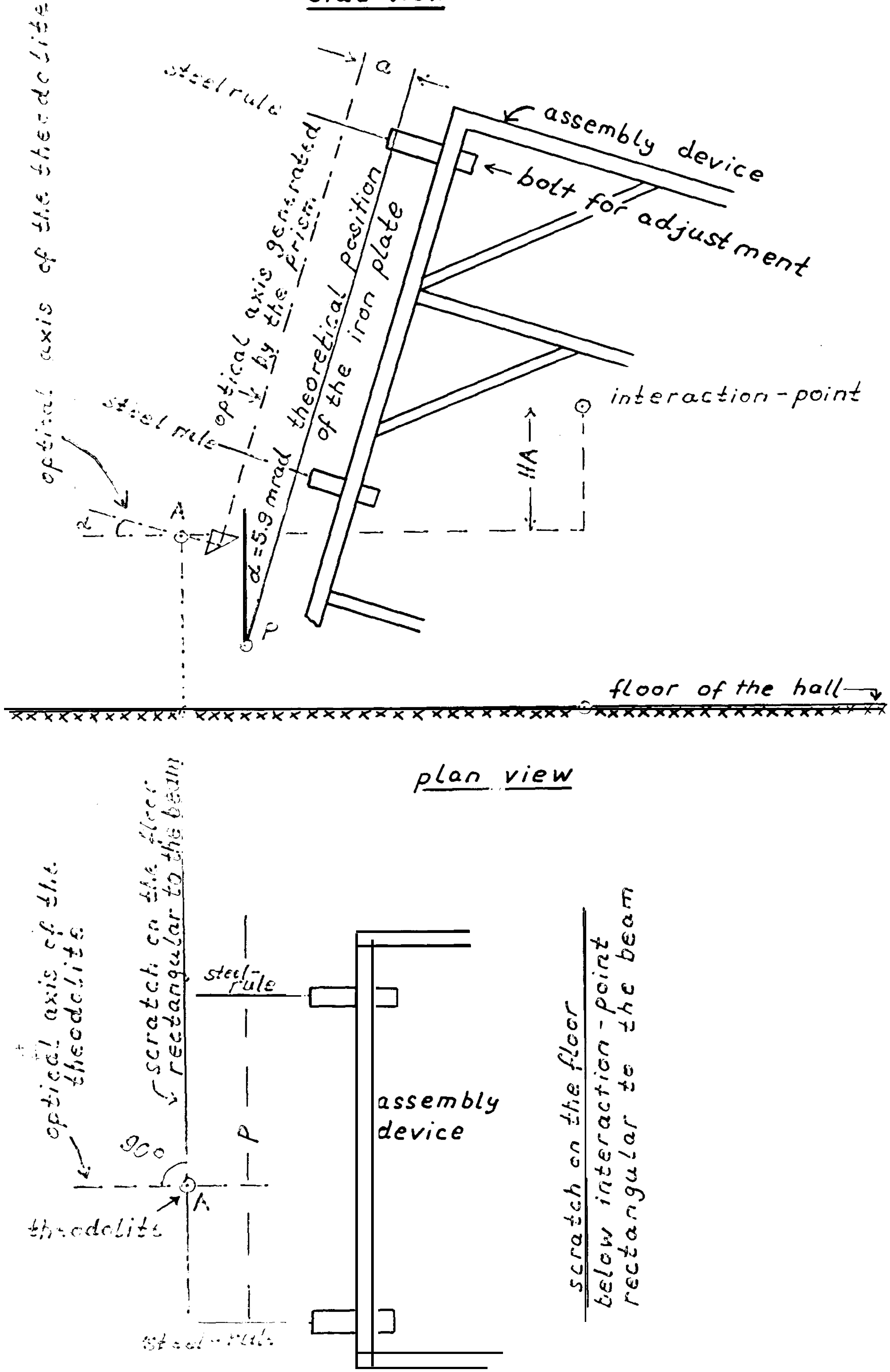


Fig. 19: Assembly-Device for Mounting of Iron-Plates (H1)

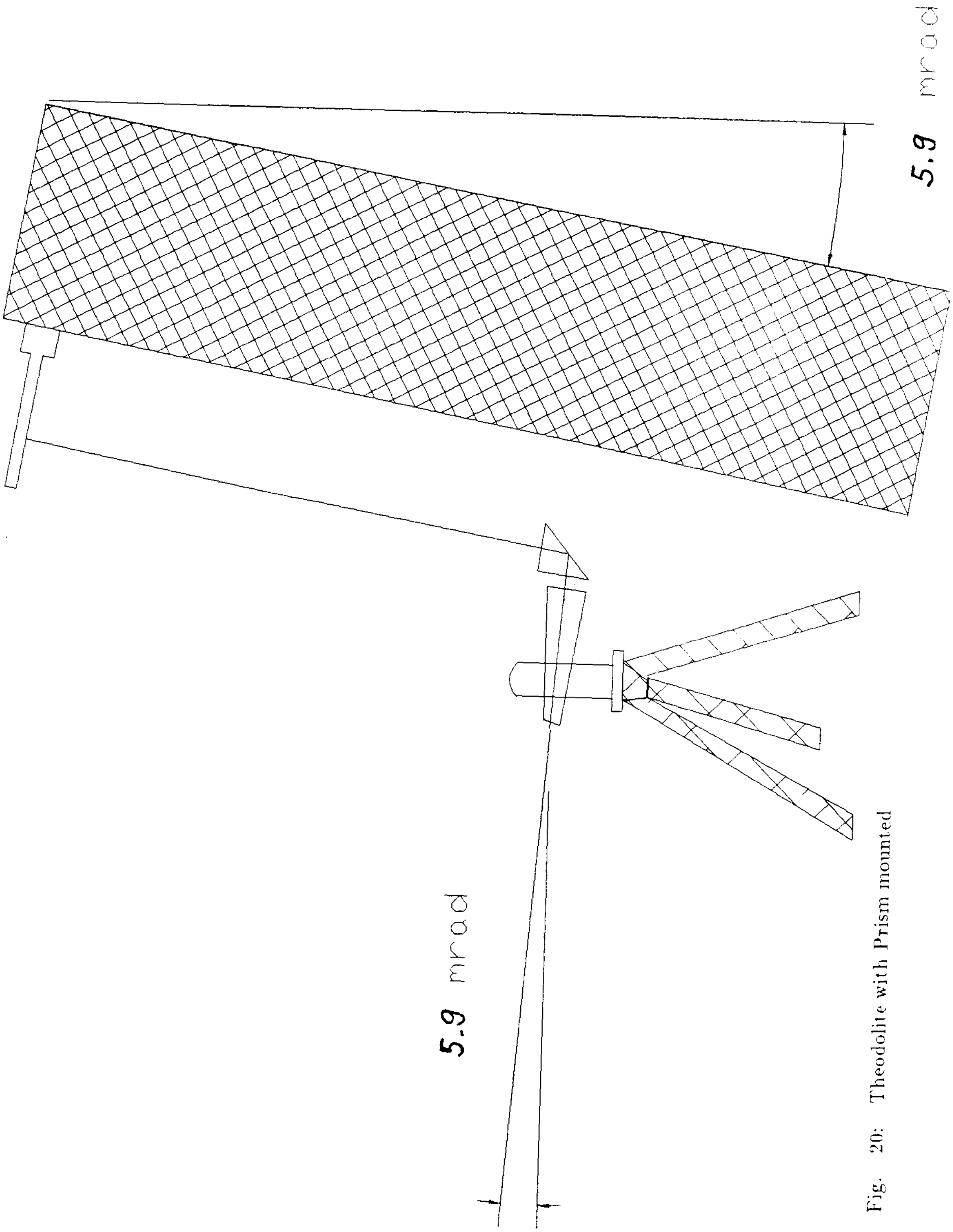


Fig. 20: Theodolite with Prism mounted

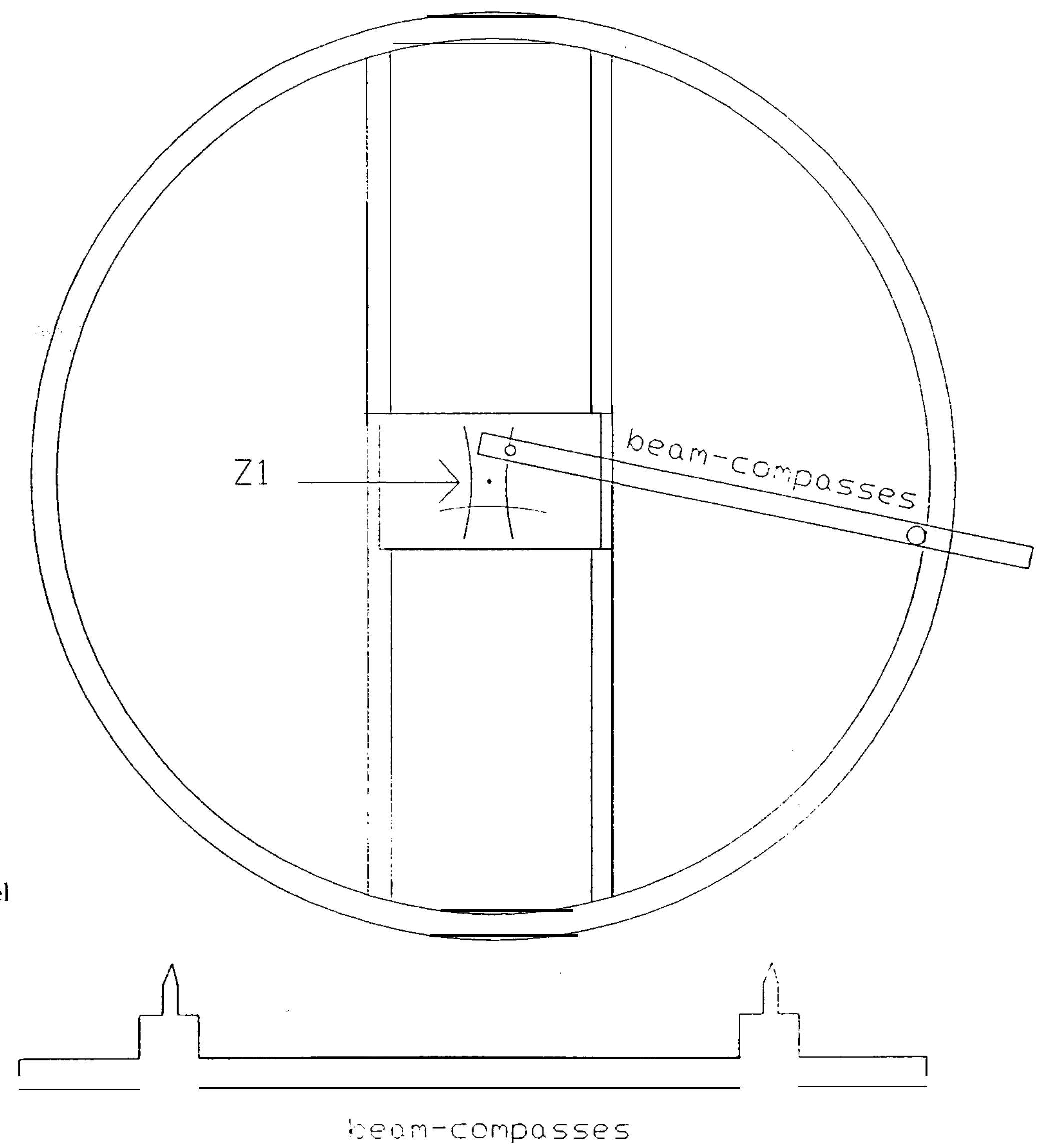


Fig. 21: Flange of Cylindrical Vessel with Beam-Compasses

Fig. 22

Form of Different Flanges as Determined

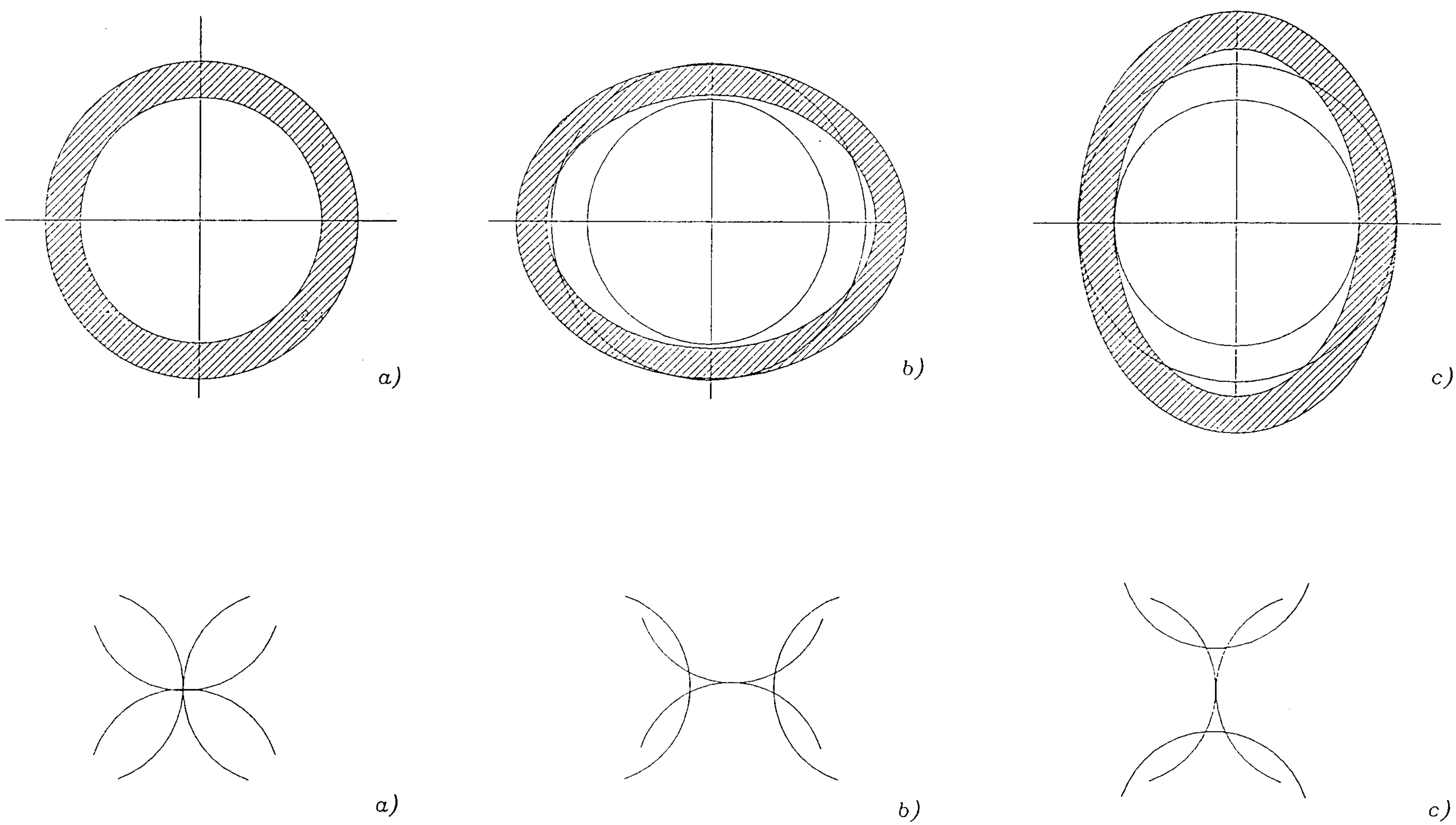


Fig. 23

Possibility of Theodolite's Stand to Look at both Centers

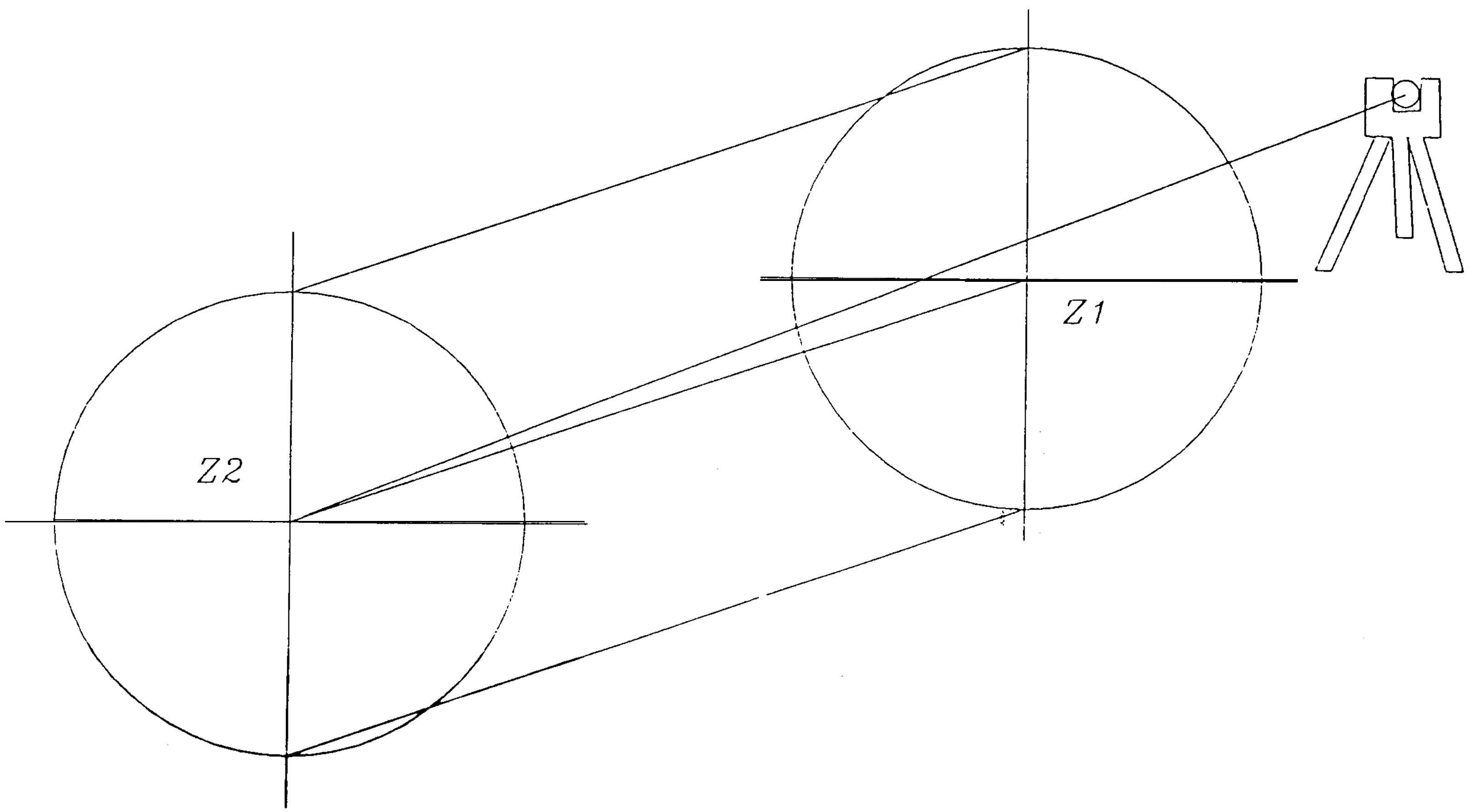
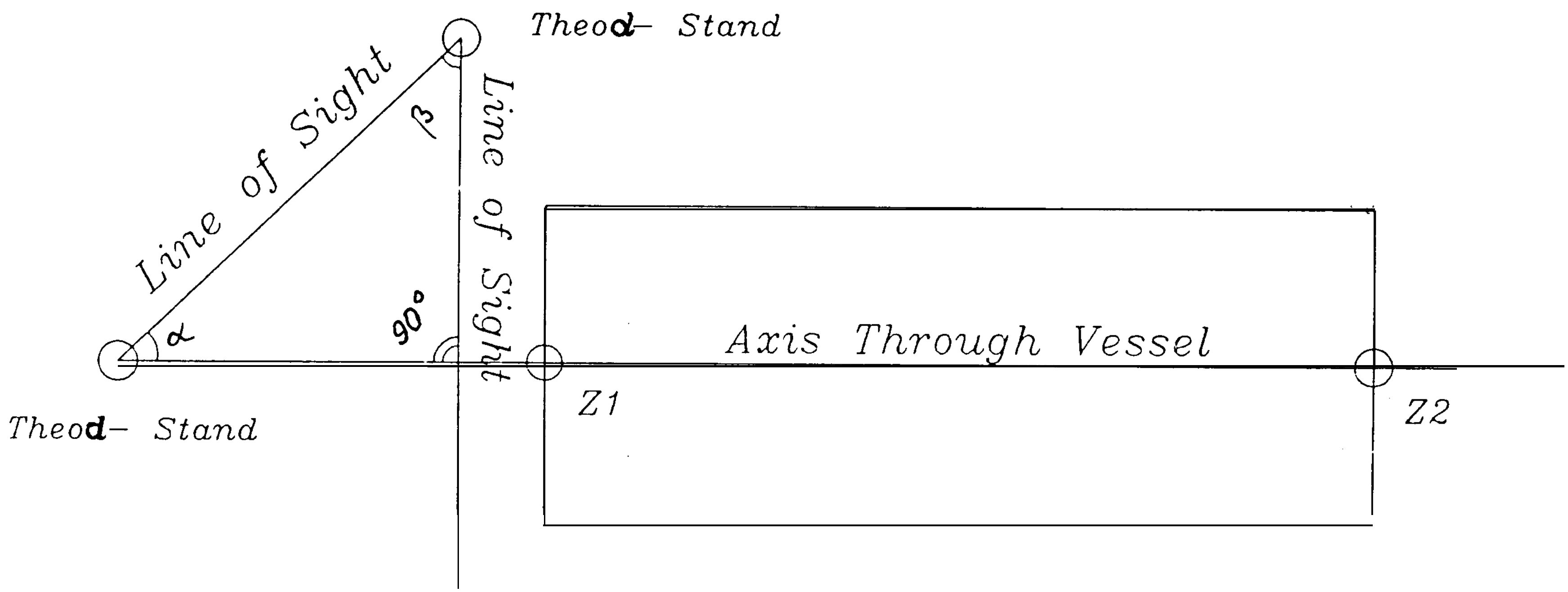


Fig. 24

Measuring – Scheme to Verify the Perpendicularity of Flange and Axis



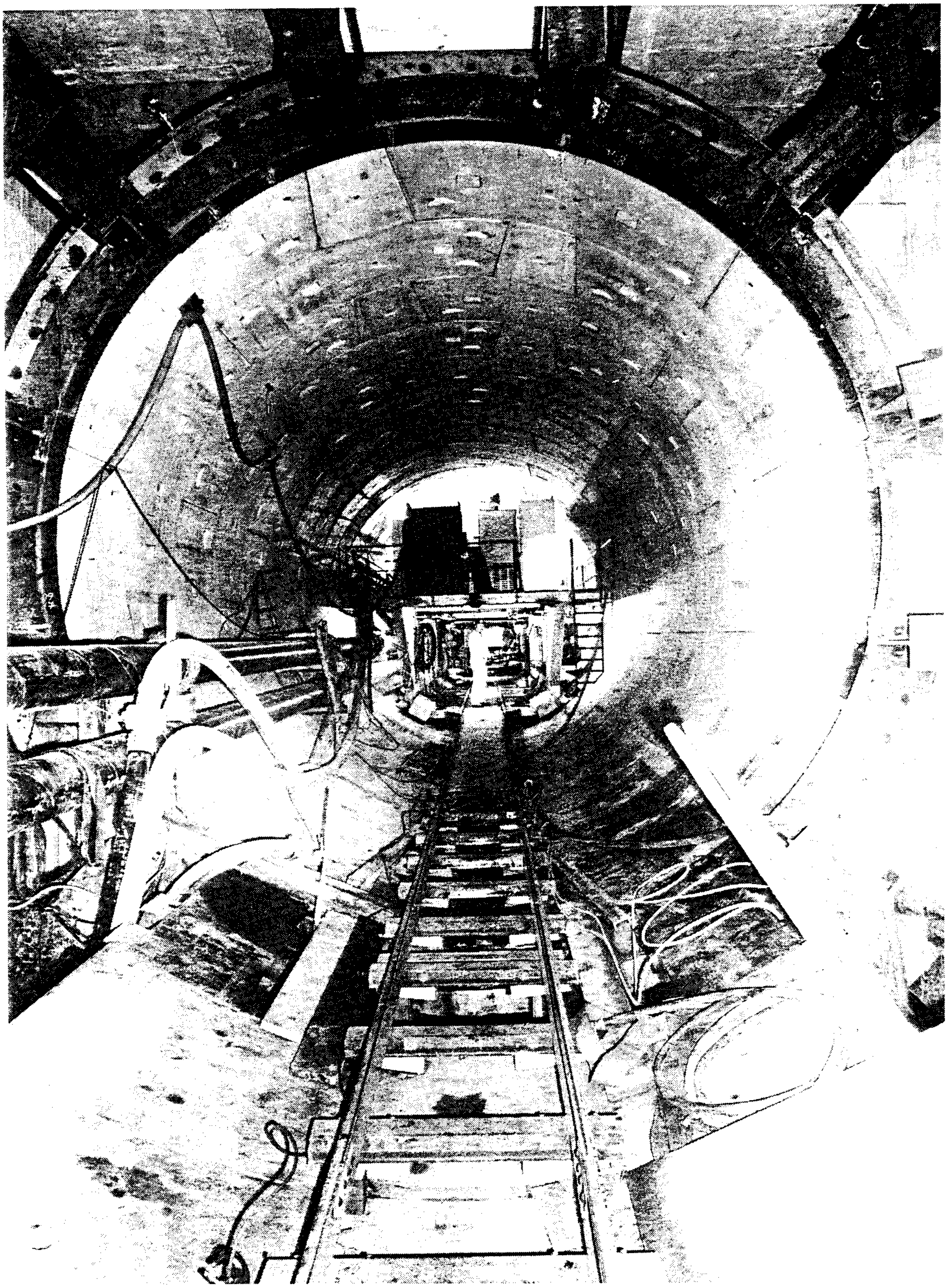


Fig. 25: View into the HERB-Tunnel (under Construction)

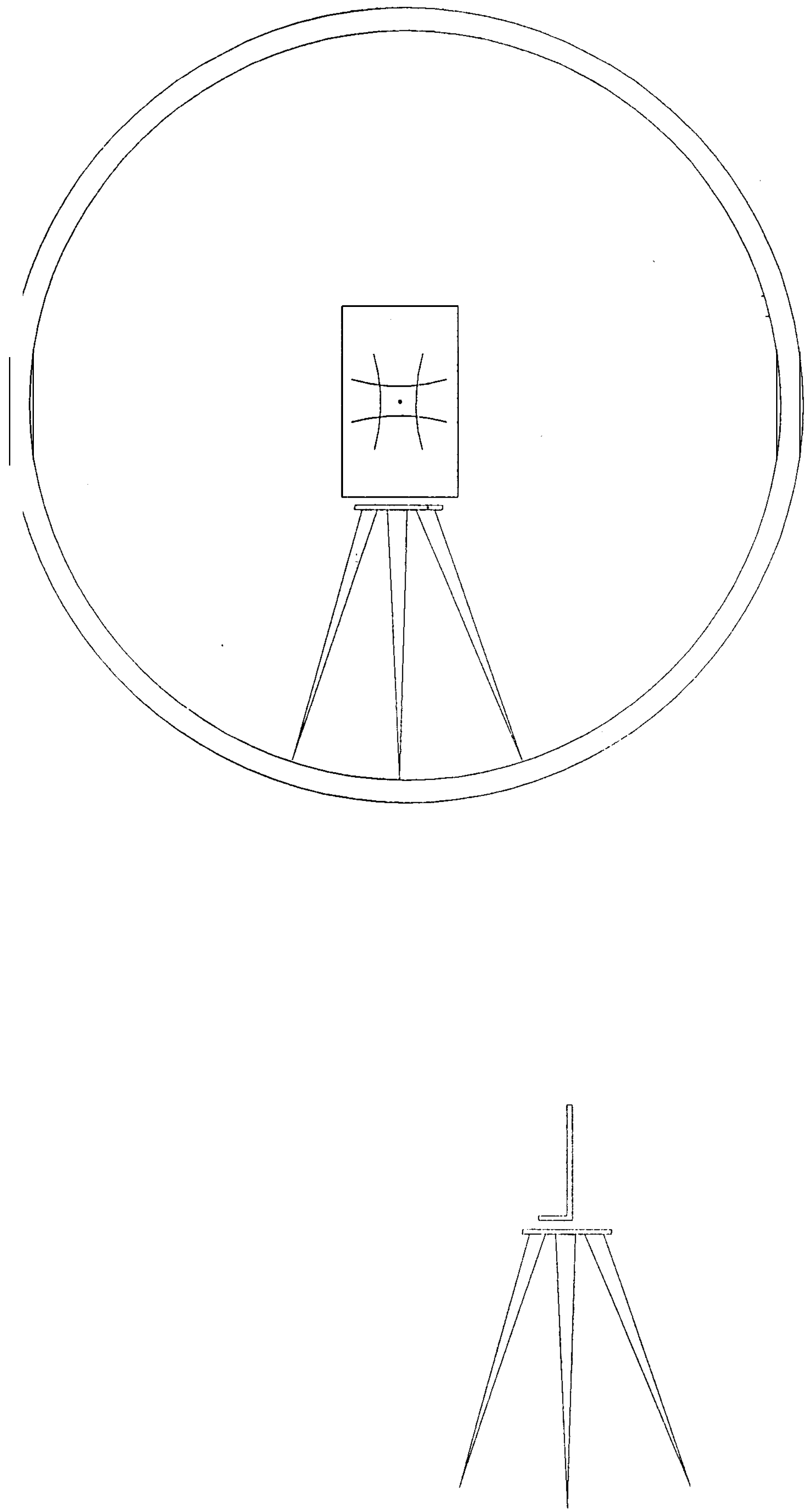


Fig. 26: Scheme of Tunnel-Profile-Measurement