EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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Design of C_4F_{10} Cherenkov detectors

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1 Simulation of π^+K^- atomic pairs

The C_4F_{10} Cherenkov detectors were designed in 2005 for particle identification in the DIRAC experiment on study of $\pi^{\pm}K^{\mp}$ atoms. To estimate the detector dimensions the pions and kaons from π^+K^- atom breakup were simulated in the DIRAC setup using GEANT (O. Gortchakov). Events were selected if π^+ and K^- were detected by all drift chambers. Then different distributions were obtained in DC2, DC3, DC4, VH, HH planes, in front of CH, in a plane of 1 m downstream of the front plane of CH, in back side of CH and in PR. If pions and kaons decay or interact before a plane they are excluded from distributions.

From the simulated space distributions the boundaries (horizontal and vertical dimensions of rectangles) and the boundary positions were determined on the planes of the downstream detectors (tab. 1).

The kaon x-boundaries and ranges are in table 1. In the table $x = 0$ cm is in a detector centre. The analogous table was prepared for the kaon y-boundaries and ranges.

Table 1: *Kaon x-boundaries and ranges.*

plane	x_1 cm	x_2 cm	Δx cm
DC4	33	64	31
VH	37	69	32
HH	39	72	33
CH1	44	82	38
CH2	60	107	47
CH3	87	153	66

2 "Kaon box" based on simulation

2.1 Full "kaon box"

The table 1 was used to draw the "kaon box". For that the vertical rectangles were drawn on DC, VH, HH, on front of CH, 1 m from front of CH and on back side of CH (fig. 1). There were also drawn hatched horizontal rectangles in order to see the beam in the top view (fig. 2). The kaon beam edges in DC4 and back of CH were connected by lines (fig. 2).

The "kaon box" touches HH and the mirrors of the N_2 CH. "Kaon box" position and dimensions are shown in figs. 3 and 4. Coordinates of the kaon source are x=-205.7 mm, y=86.0 mm. The magnet centre is in the point x=0 mm, y=0 mm. Rotation angle is 7.7°, angular apertures in horizontal and vertical planes are 5.4° and 2.0°, respectively. Distance from the kaon source to the front side of the "kaon box" is 3726.6 mm. The box length is 2802 mm.

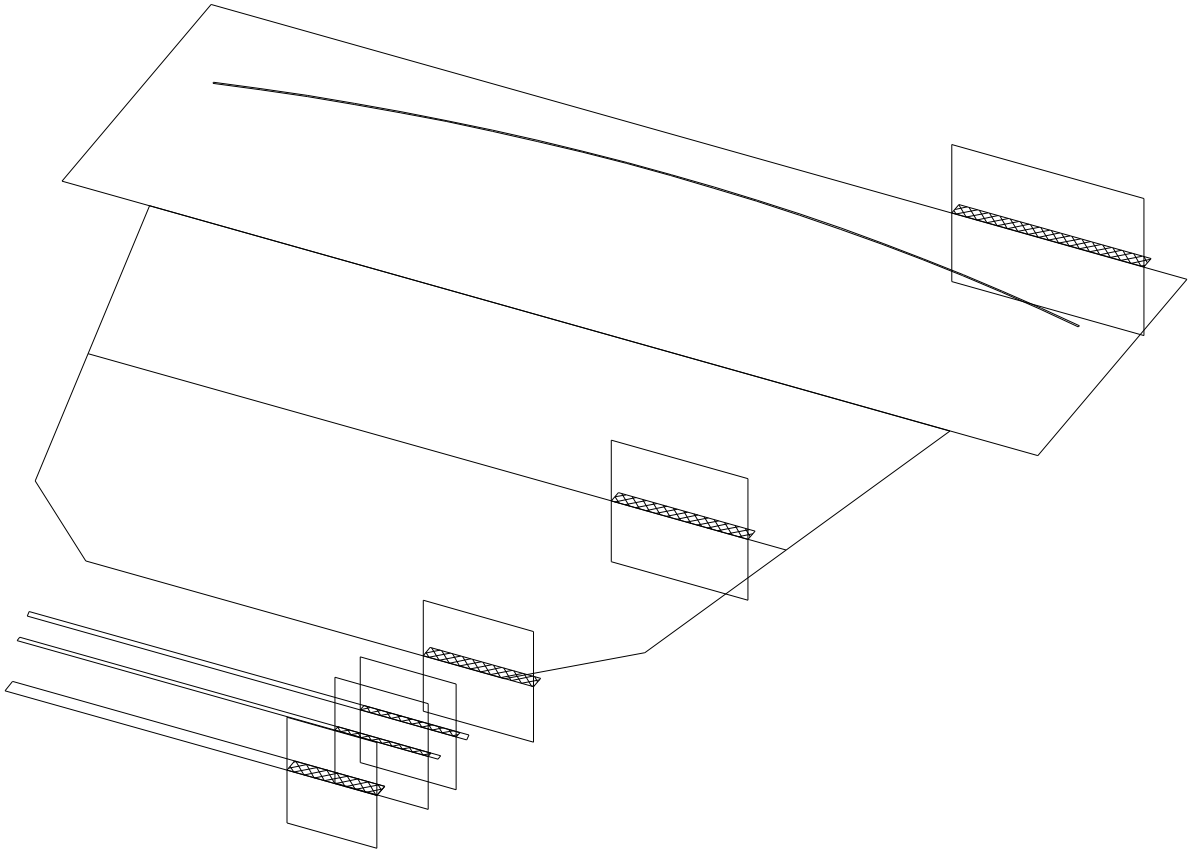

Figure 1: *DC4, VH, HH, CH1, CH2, CH3 and verical and horizontal rectangles to display kaon beam dimensions.*

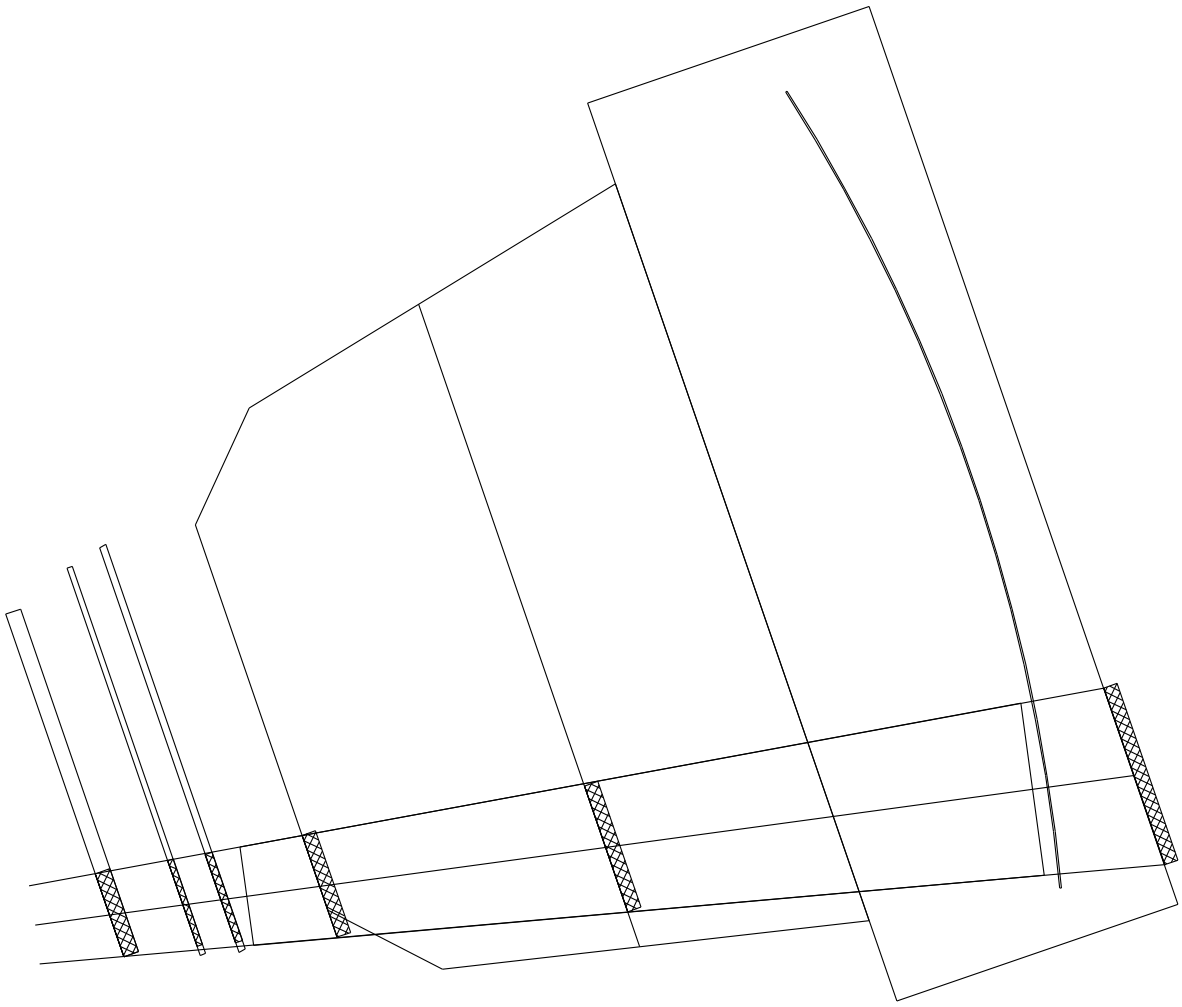

Figure 2: *Top view of DC4, VH, HH, CH1, CH2, CH3, hatched rectangles and "kaon box".*

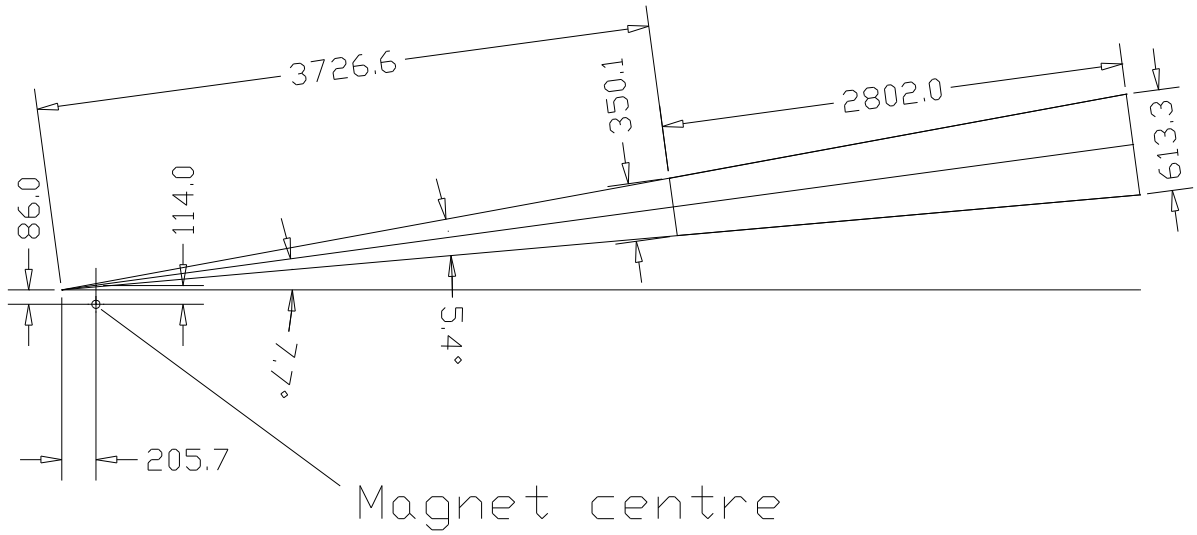

Figure 3: *"Kaon box" position and dimensions, top view. Coordinates of the kaon source are x=-205.7 mm, y=+86.0 mm. Coordinates of the magnet centre are x=0 mm, y=0 mm. Rotation angle is* 7.7°*, angular aperture is* 5.4°*. Distance from the kaon source to the front side of the "particle box" is 3726.6 mm.*

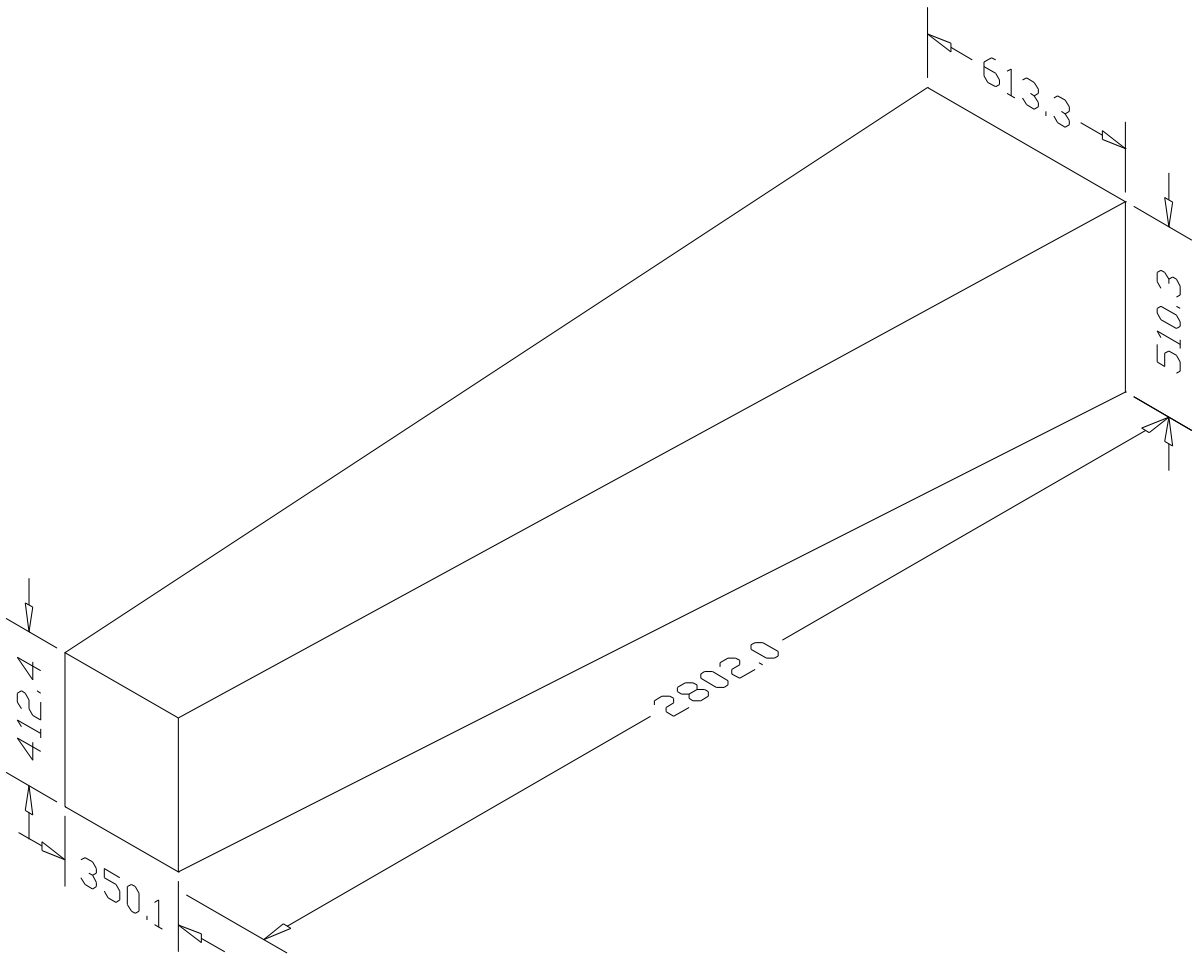

Figure 4: *"Kaon box" dimensions.*

2.2 C_4F_{10} "particle boxes" and "light boxes"

The "kaon box" (fig. 4) was cut from the front side by 650 mm to clear space for the aerogel detectors and from the back side by 1202 mm to keep ~ 7 photoelectrons for N_2 detector. The length of C_4F_{10} detector including the spherical mirror system is $2802 - 650 - 1202 = 950$ mm. The length for Cherenkov radiation is shorter by 70 mm: $950 - 70 = 880$ mm. Corresponding "particle box" is in fig. 5.

"Light box" for the C_4F_{10} detector should be wider because it is necessary to add to the "particle box" the Cherenkov radiation angle for electrons ($\theta = 3.03°$). Corresponding light box is in fig. 6. The Cherenkov light is collected by 4 PMs. So to estimate the spherical mirror dimensions there was only needed 1/4 part of the "light box" (fig. 7).

Because of symmetry of the "particle box" relative to the horizontal and vertical median planes there was enough to trace the Cherenkov light using only 1/4 part of the "particle box". Moreover because of symmetry of the reflecting surface of the spherical mirror relative the vertical median plane of 1/4 part of the "particle box" there was enough to trace the Cherenkov light using only 1/8 part of the "particle box". To fix the representative cones of Cherenkov radiation to 1/8 part of the "particle box" this part was divided in two parts (1/16+1/16) by "horizontal" median plane (fig. 8).

1/8 of the "particle box" is in fig. 9. Back side of this box was corrected to be perpendicular to the edge AB.

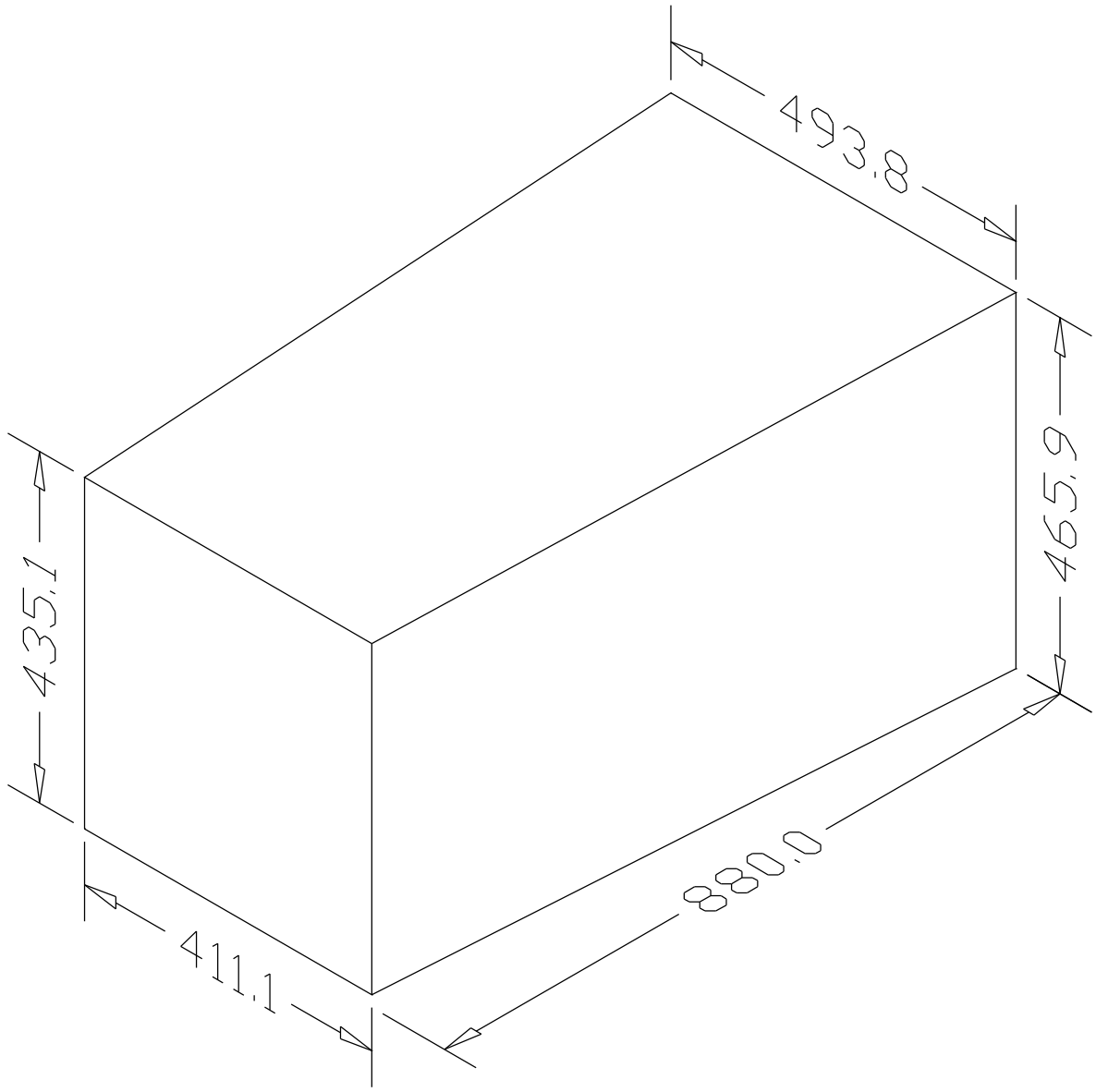

Figure 5: *"Particle box" from front of the counter to the spherical mirror apex.*

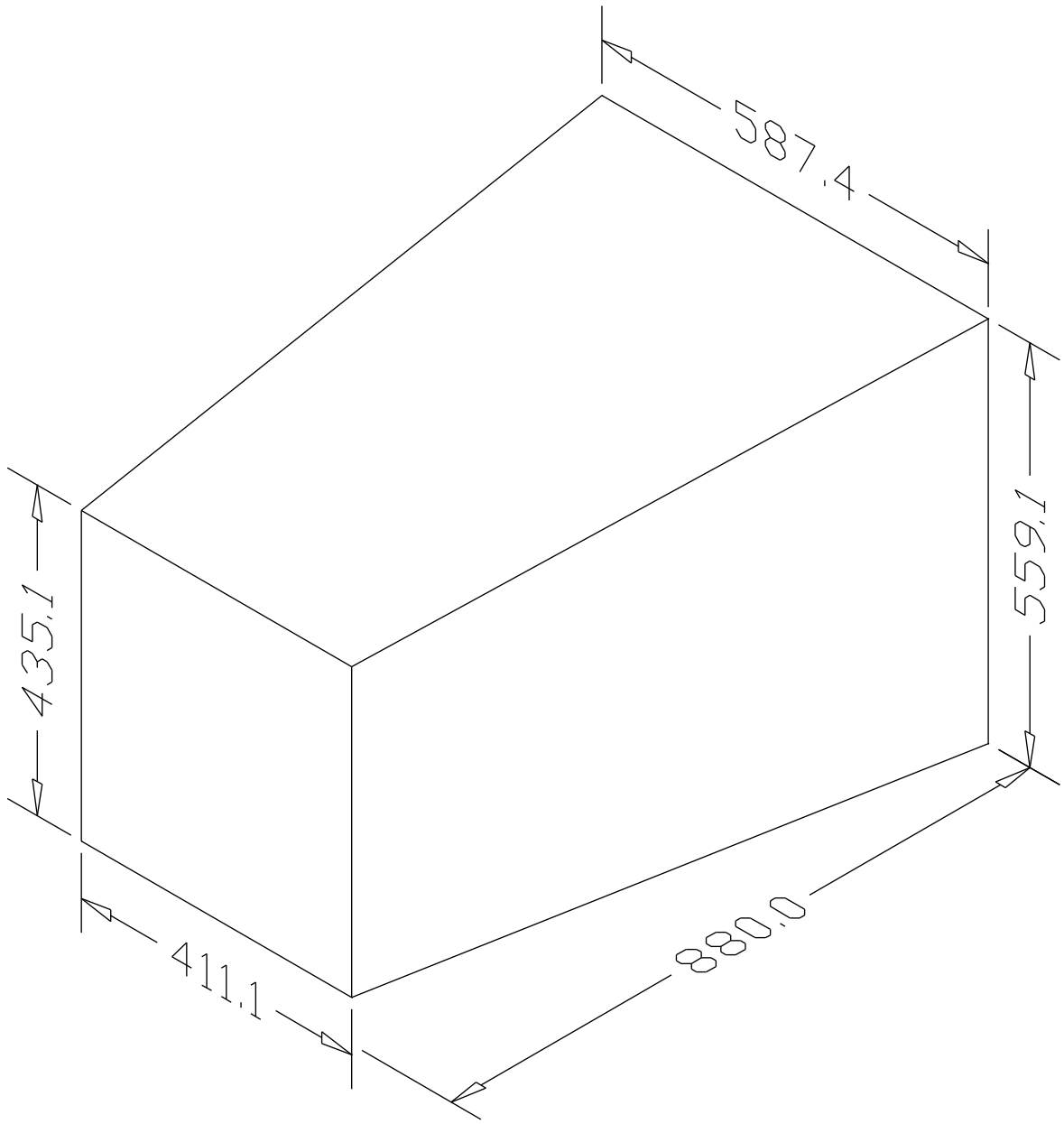

Figure 6: *"Light box" from front of the counter to the spherical mirror apex.*

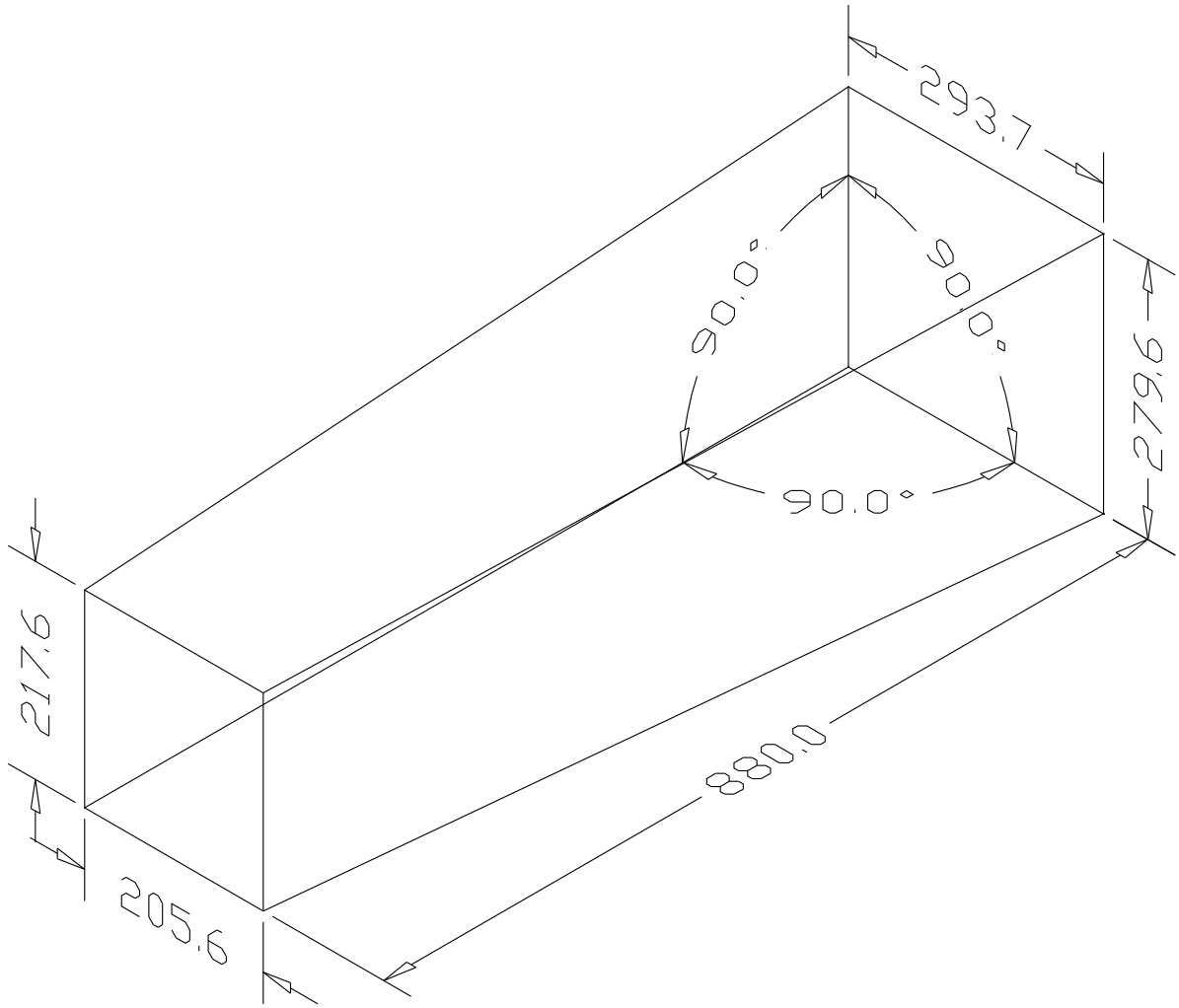

Figure 7: *1/4 part of the "light box" from front of the counter to the spherical mirror apex.*

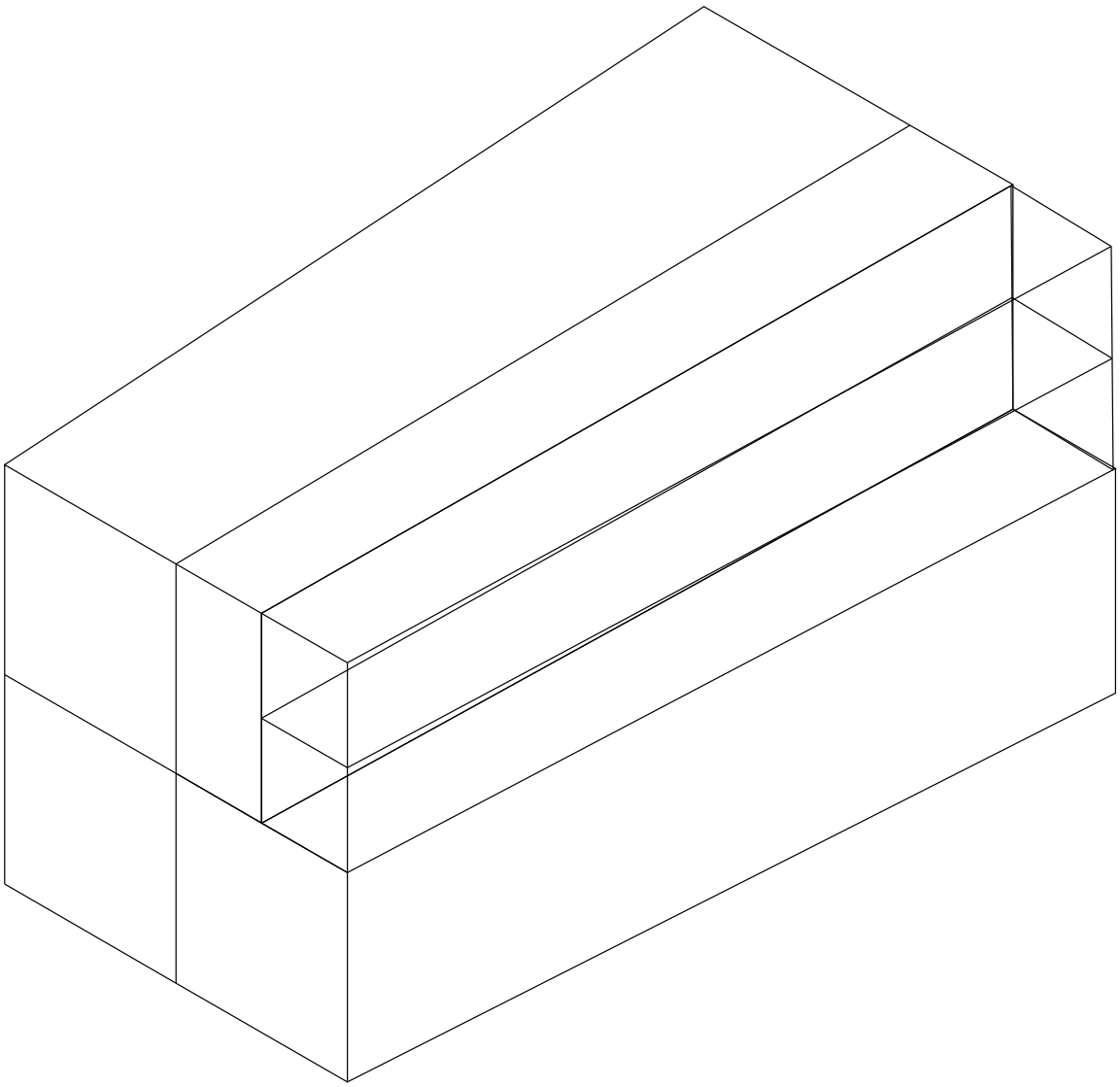

Figure 8: *"Particle boxes" and "subboxes" up to 1/16 of the full "particle box".*

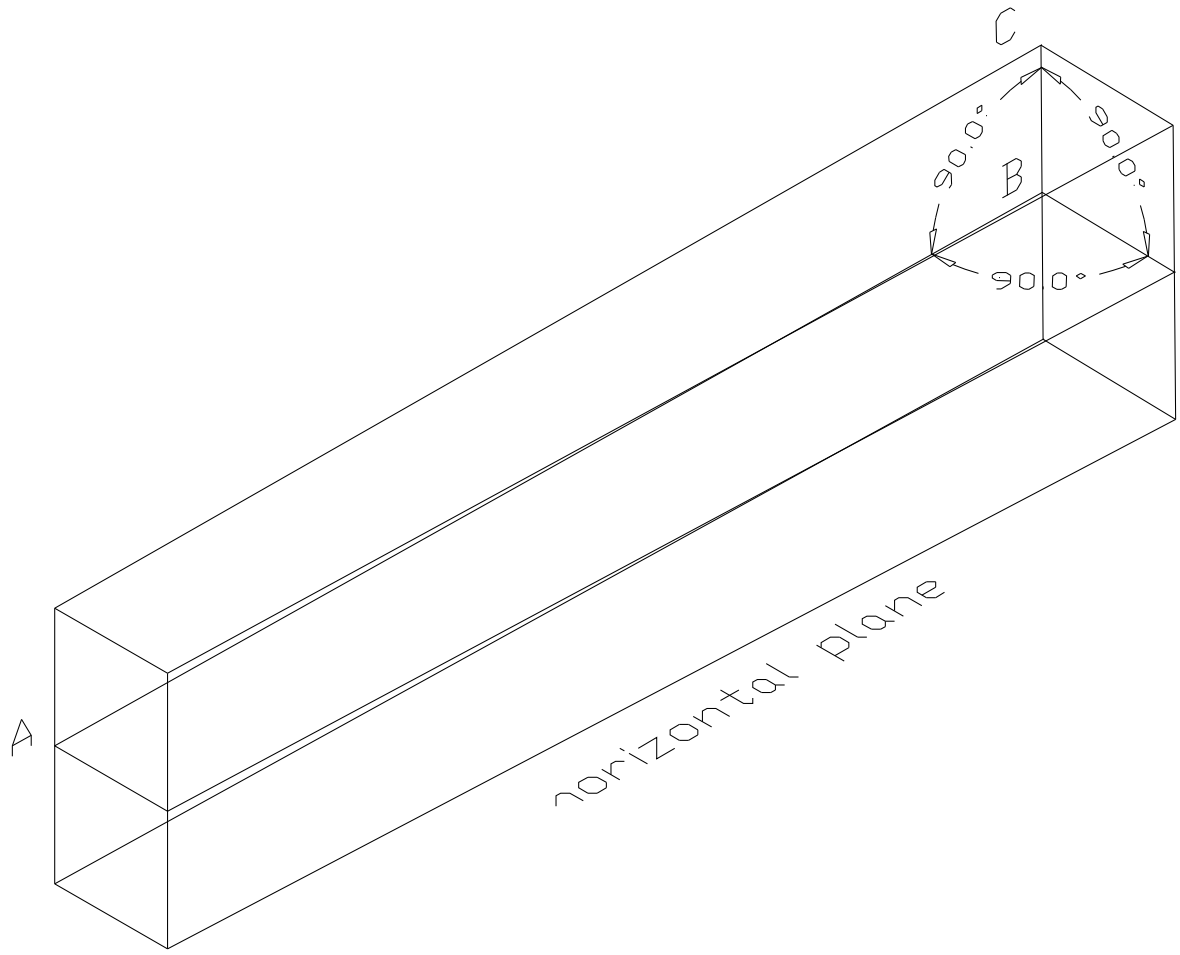

Figure 9: *1/8 (1/16+1/16) part of the "particle box".*

3 Mirrors, light cones, direct and reflected light, rings

3.1 Spherical mirrors

The spherical mirrors have curvature radius of 1194 mm as in the existing CH. The sphere apex is attached to the back side of 1/8 part of the "particle box" (point B in fig. 9). The median plane of 1/8 part of the "particle box" is at 0.5° relative to the horizontal plane. At the beginning the sphere centre was on the line AB. Then the sphere was rotated in the plane ABC relative to the point B by 14°. Finally the sphere was cut so that the mirror dimensions in the front view became the same as the dimensions of the back side of 1/4 of the "light box" (fig. 7). This means that the left and bottom mirror sides were cut along the left and bottom faces of 1/4 part of the "light box" and the right and upper mirror sides were cut in directions parallel to the left and bottom sides of the "light box" (fig. 10).

It is necessary to mention that the sphere in the initial position (before rotation by 14°) is already rotated in the "horizontal" plane by the angle equal to 1/4 of the kaon beam divergency: $5.4°/4 = 1.35°$ (see fig. 3 and also fig. 9 where the back side of the 1/8 of the "particle box" is corrected to be perpendicular to the edge AB). At this condition the PM position is optimal.

These mirrors are asymmetrical (left and right). Upper left and bottom right mirrors are identical. Upper right and bottom left ones are mirrored to the previous two mirrors. The spherical mirrors are in figs. 11, 12, 13, 14.

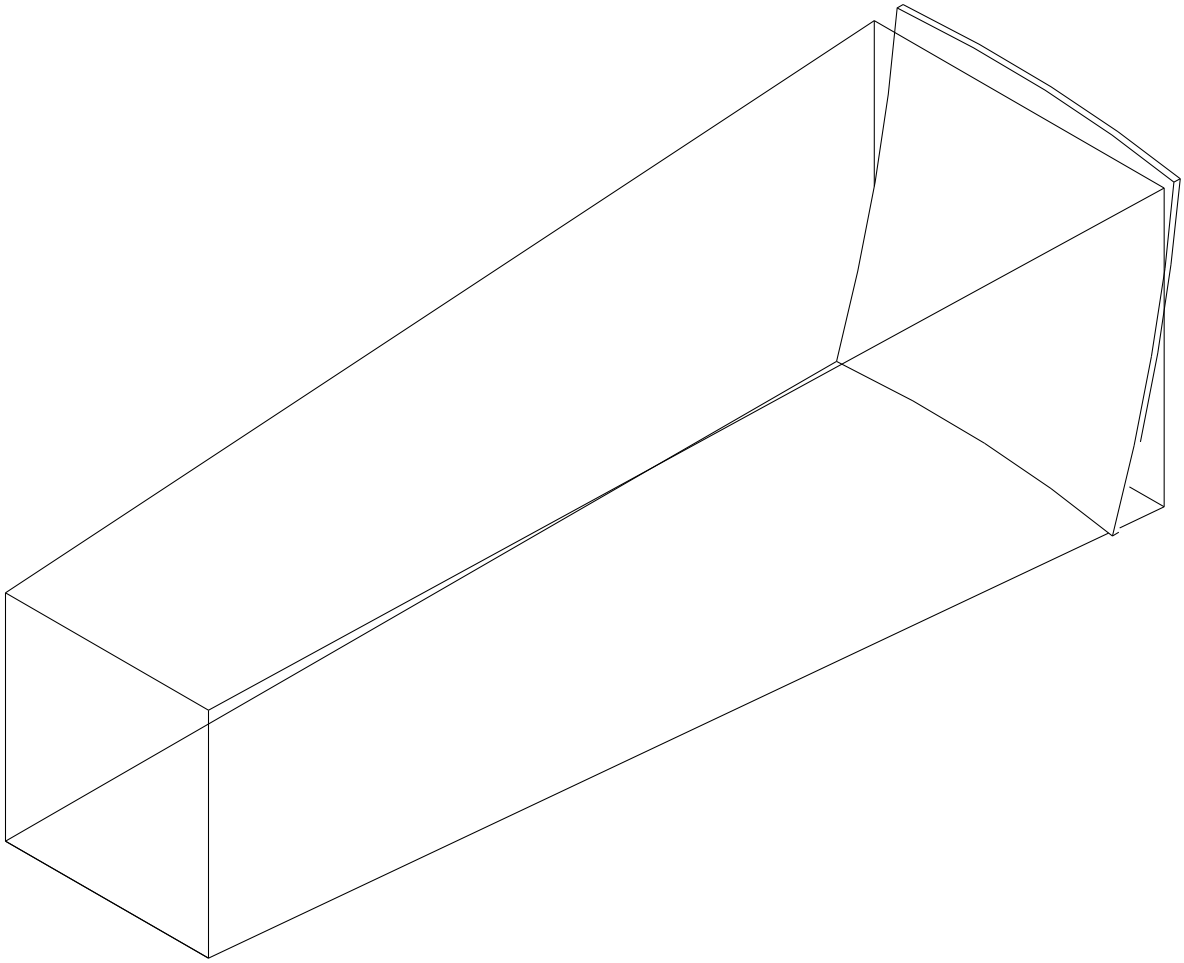

Figure 10: *1/4 part of the "light box" and the spherical mirror in final position.*

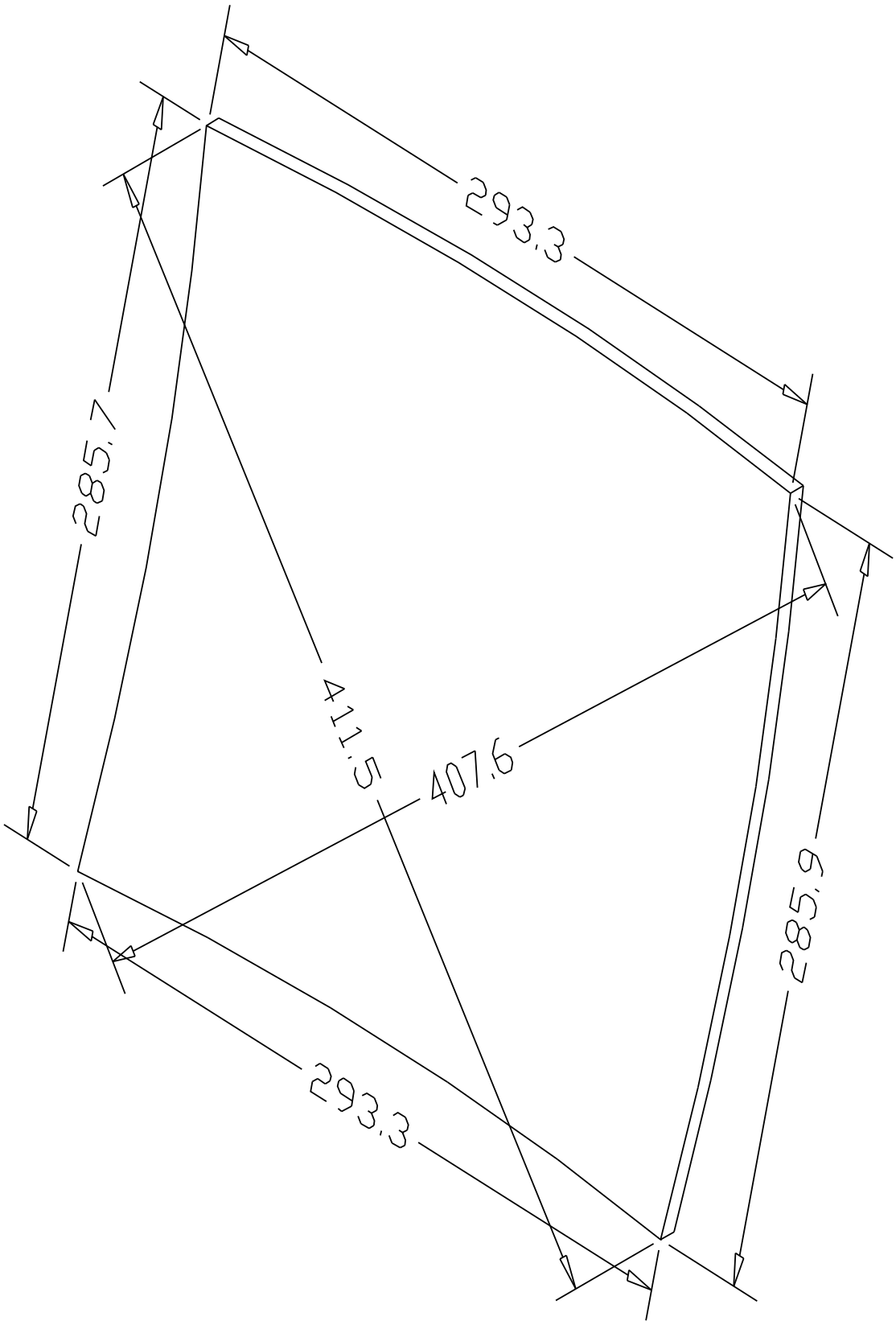

Figure 11: *Spherical mirror top right.*

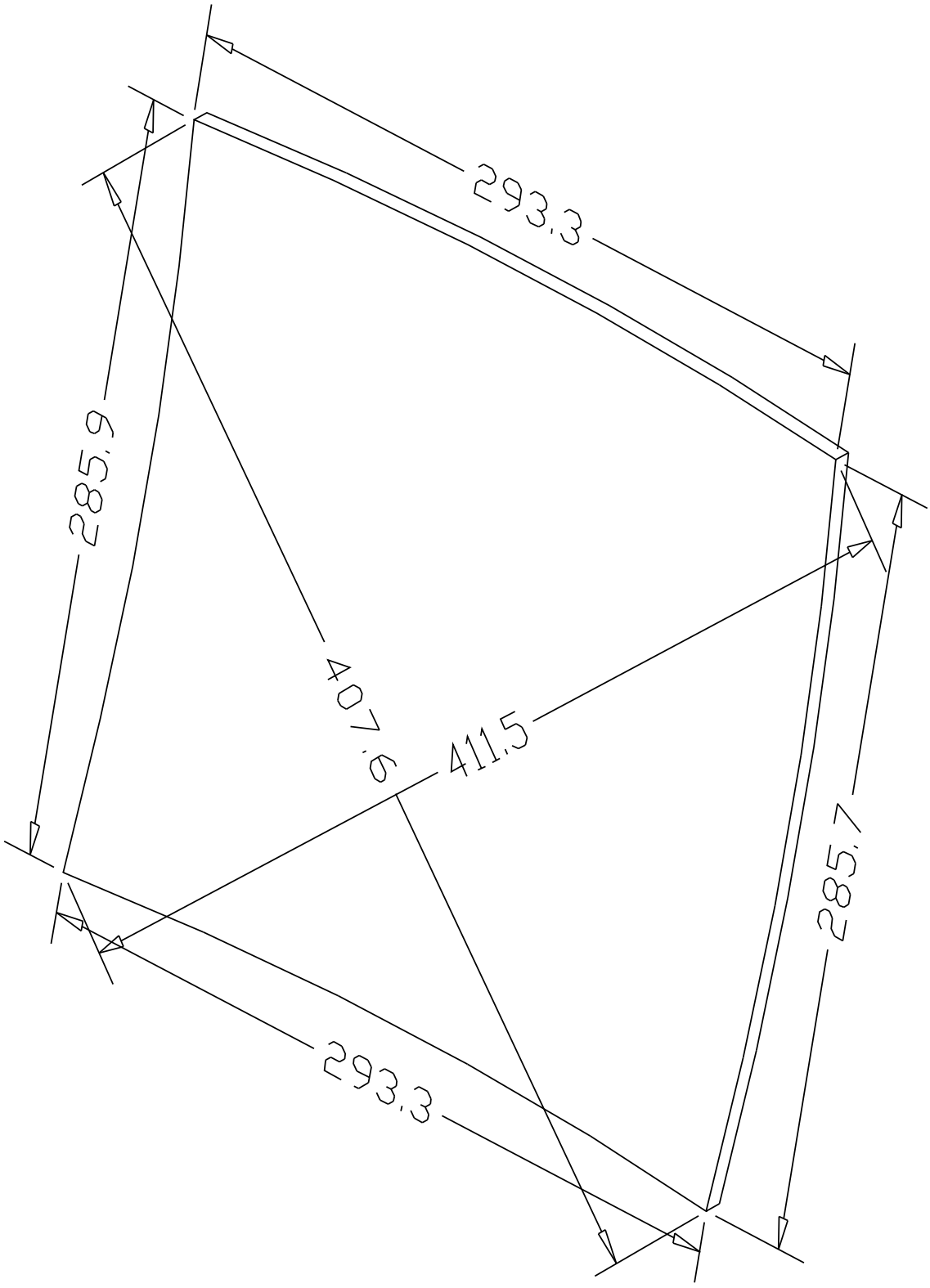

Figure 12: *Spherical mirror top left.*

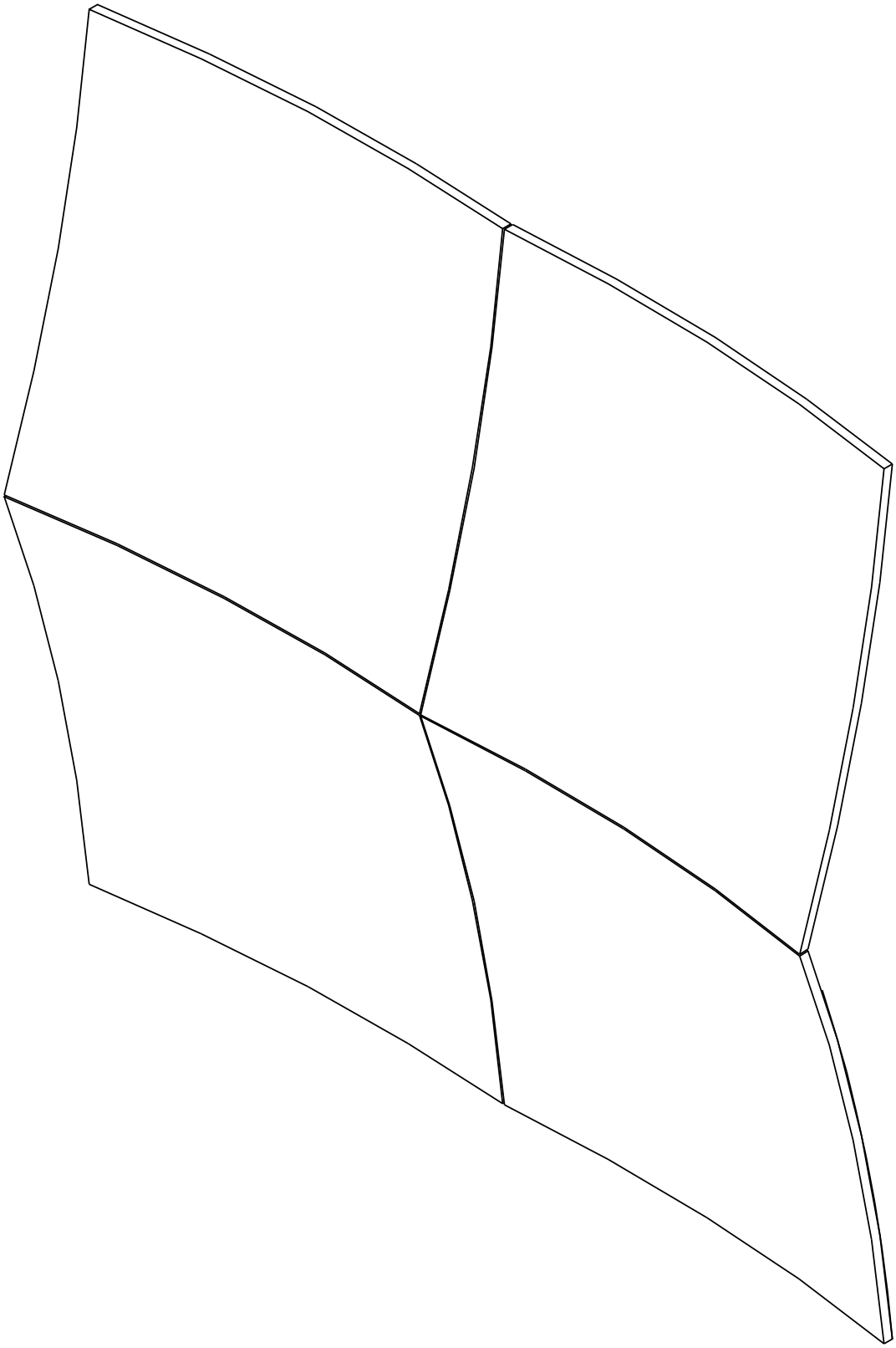

Figure 13: *Four spherical mirrors.*

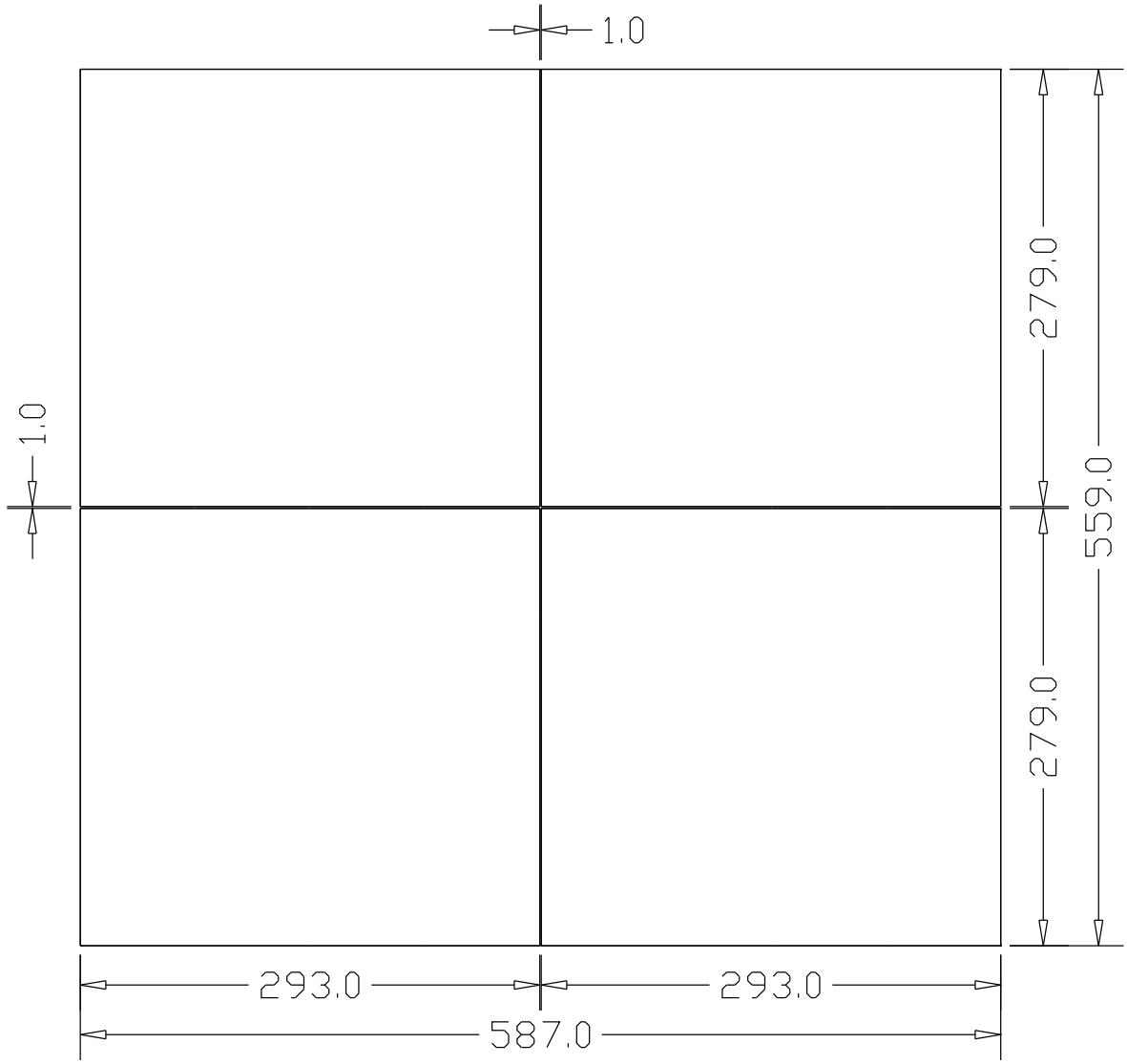

Figure 14: *Front view of the four spherical mirrors.*

3.2 Light cones, direct and reflected light

Along the edges of "subboxes" (1/16+1/16 parts of the "particle box") there were drawn 6 cones with angles of 3.03° corresponding to Cherenkov radiation at $\beta = 1$. Later there were added two additional cones. The 8 cones were cut by the spherical mirror (fig. 15).

On every of the 8 cones there were drawn 4 "orthogonal" light trajectories from the cone apex to the mirror (direct light). This light arises on the entrance window of the detector. The light from one of 8 cones is shown in fig. 16.

Then the end points of the direct light trajectories were moved to the central points on the bases of the cones. This light imitates the light arising near the mirror. The light from one of 8 cones is shown in fig. 17.

The light from the entrance window of the detector and from the mirror was reflected by the mirror (reflected light). For every light trajectory the reflection was made in the corresponding coordinate system: light trajectory + centre of the sphere. Then the direct and reflected light was combined together and reflected relative to the vertical symmetry plane ABC (fig. 9). Direct and reflected by spherical mirror light is shown in fig. 18.

The light arising near the mirror after reflection has no distortions. A circular cone is transformed to another circular cone.

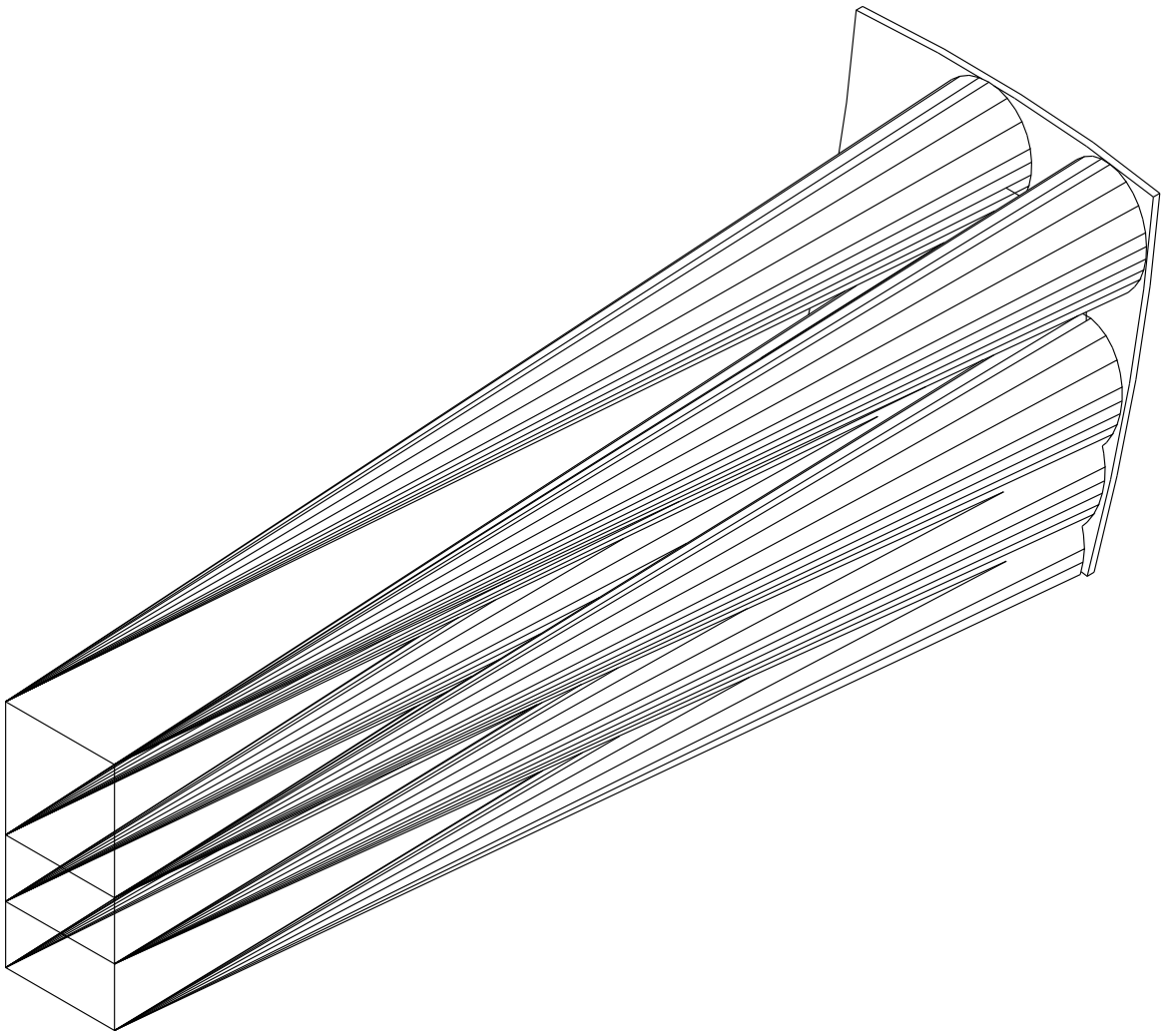

Figure 15: *1/8 (1/16+1/16) part of "particle box", 8 light cones and the top right spherical mirror.*

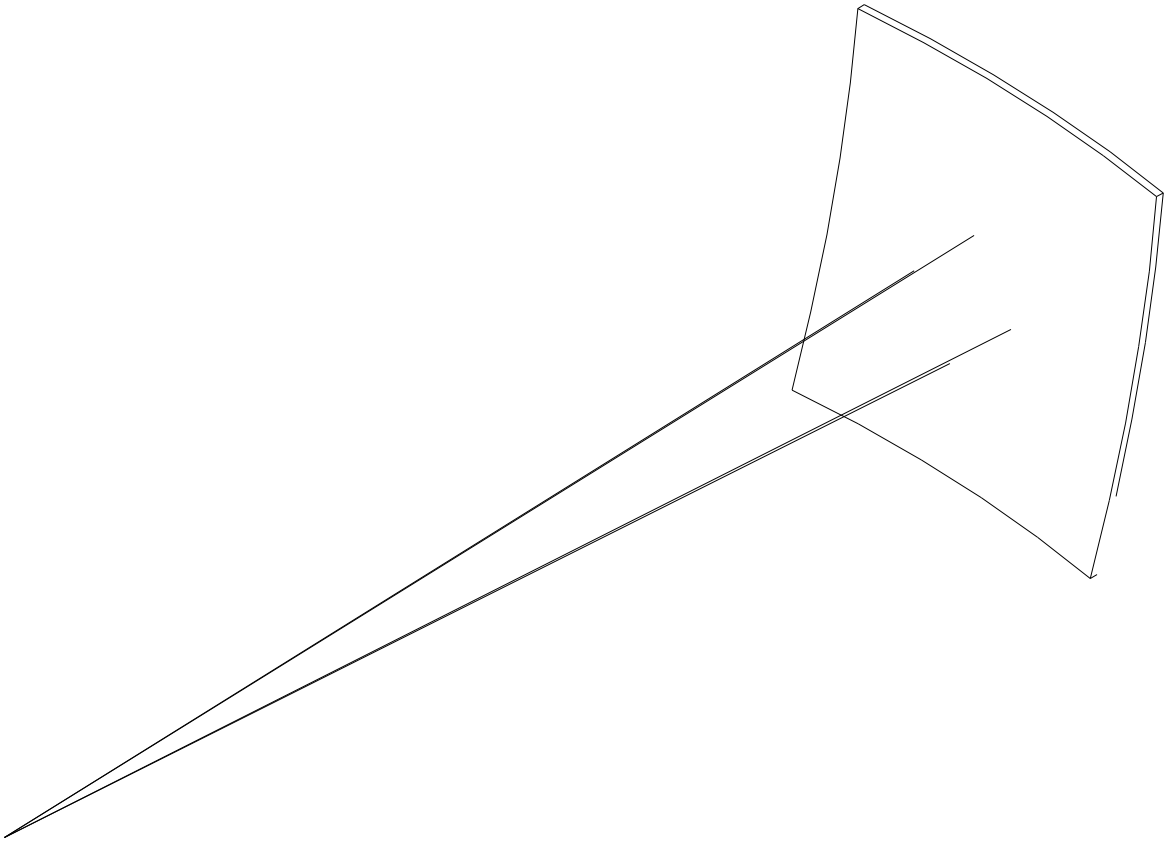

Figure 16: *Light corresponding to one of 8 cones arising in the entrance window of the detector. 4 lines.*

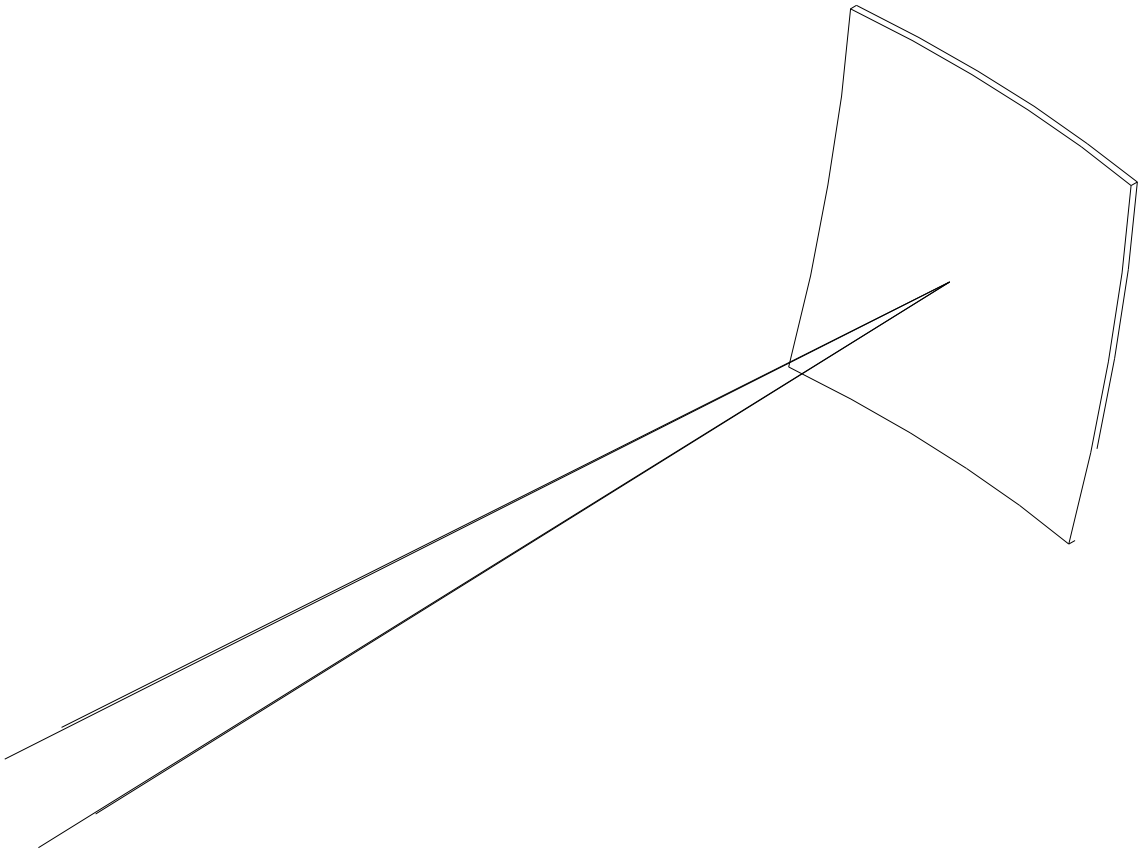

Figure 17: *Light corresponding to one of 8 cones arising on the spherical mirror. 4 lines.*

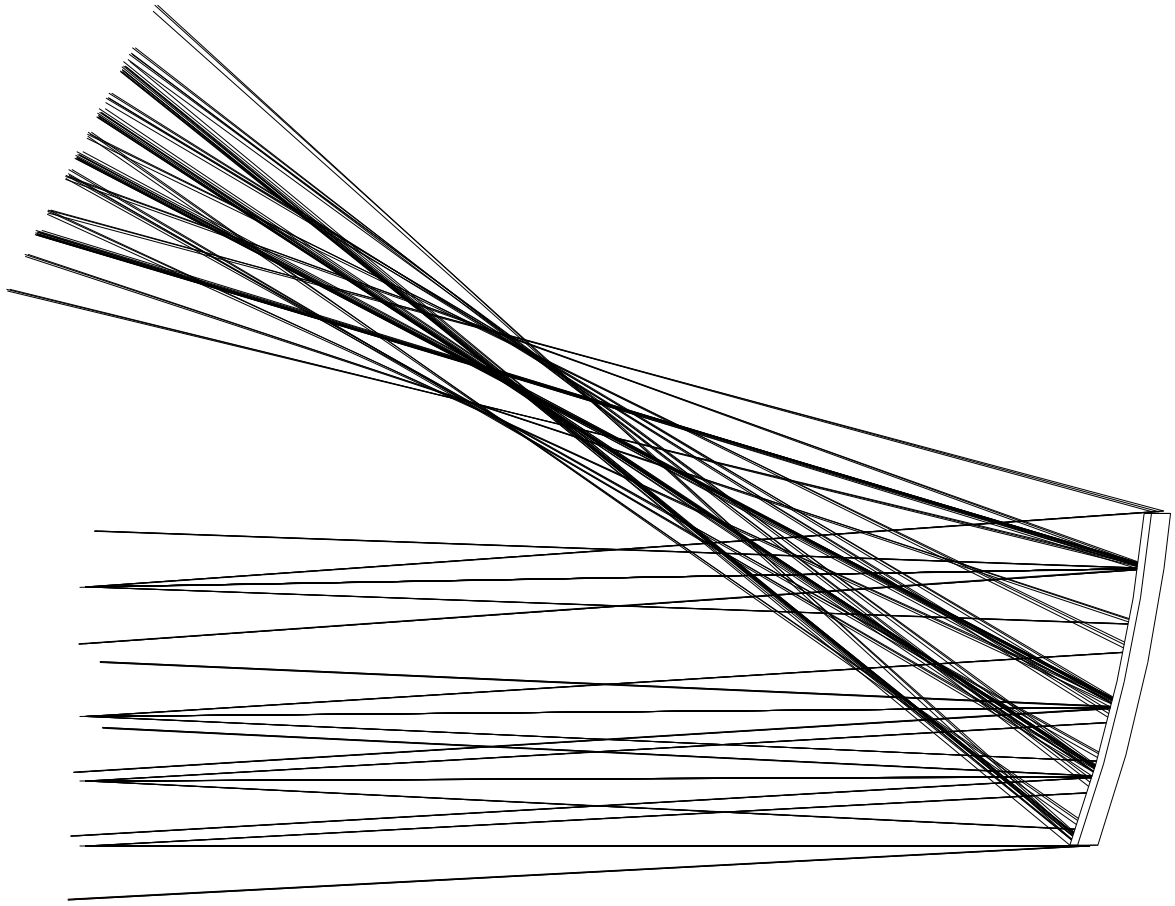

Figure 18: *Direct light from the entrance window of the detector and from the spherical mirror, spherical mirror and reflected light.*

3.3 Flat mirrors, photomultipliers, Cherenkov rings

In the exising setup geometry it is immpossible to send the light reflected from the spherical mirrors to the photomultipliers directly.

In this case PMs of C_4F_{10} detectors would interfere with PMs of the aerogel detectors. So there were used flat mirrors to reflect Cherenkov light backwards. The position and dimensions (185×185 mm^2) of the flat mirrors were properly chosen. The direct and reflected light from the spherical and flat mirrors is in fig. 19.

After that the position of photomultipliers was fixed (figs. 20, 21 and 22). In fig. 22 the all design of the detector really is shown. Cherenkov rings on the flat mirror and on the PM photocatode are in figs. 23 and 24.

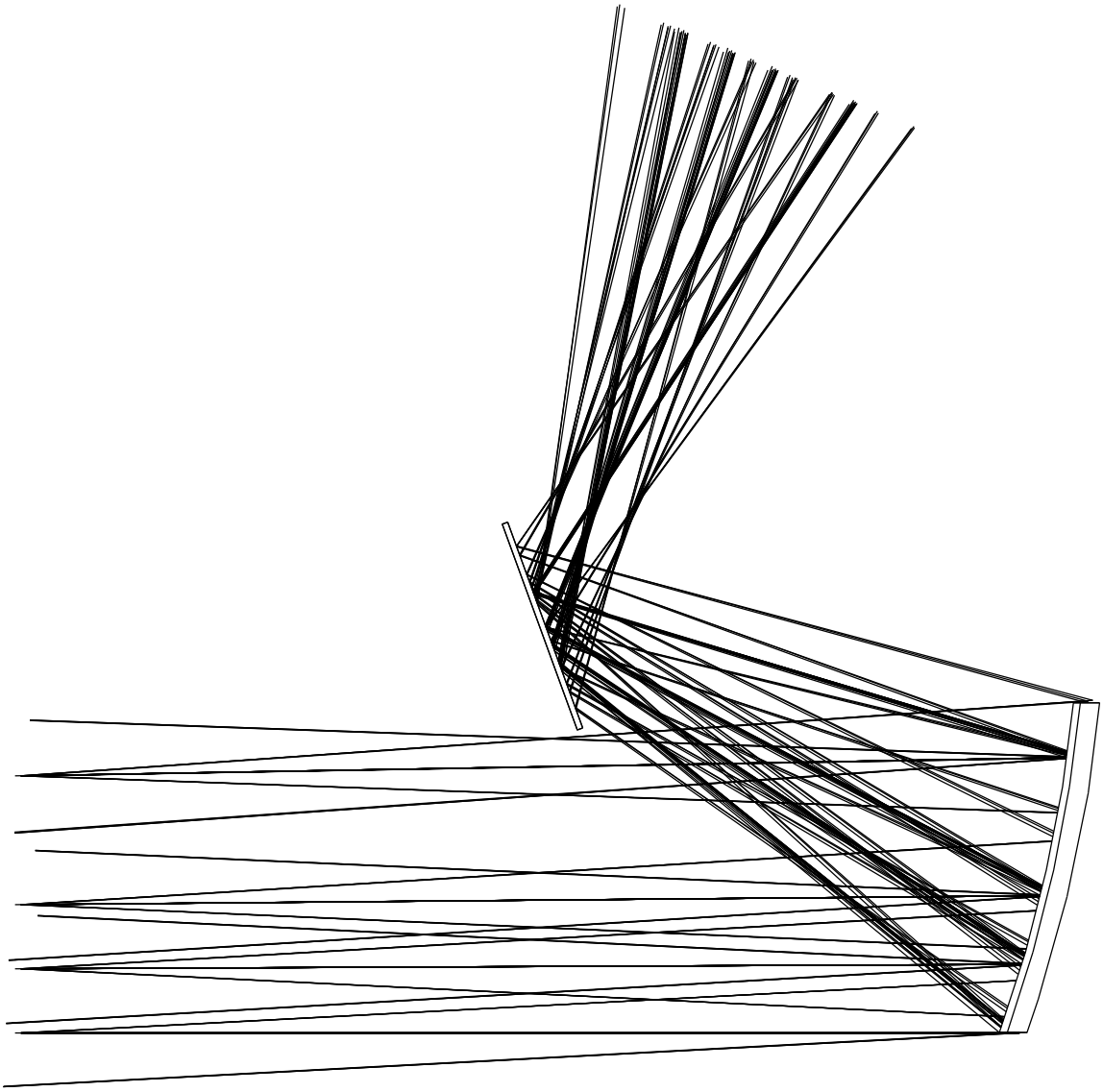

Figure 19: *Direct light, spherical mirror, reflected light from the spherical mirror, flat mirror and reflected light from the flat mirror.*

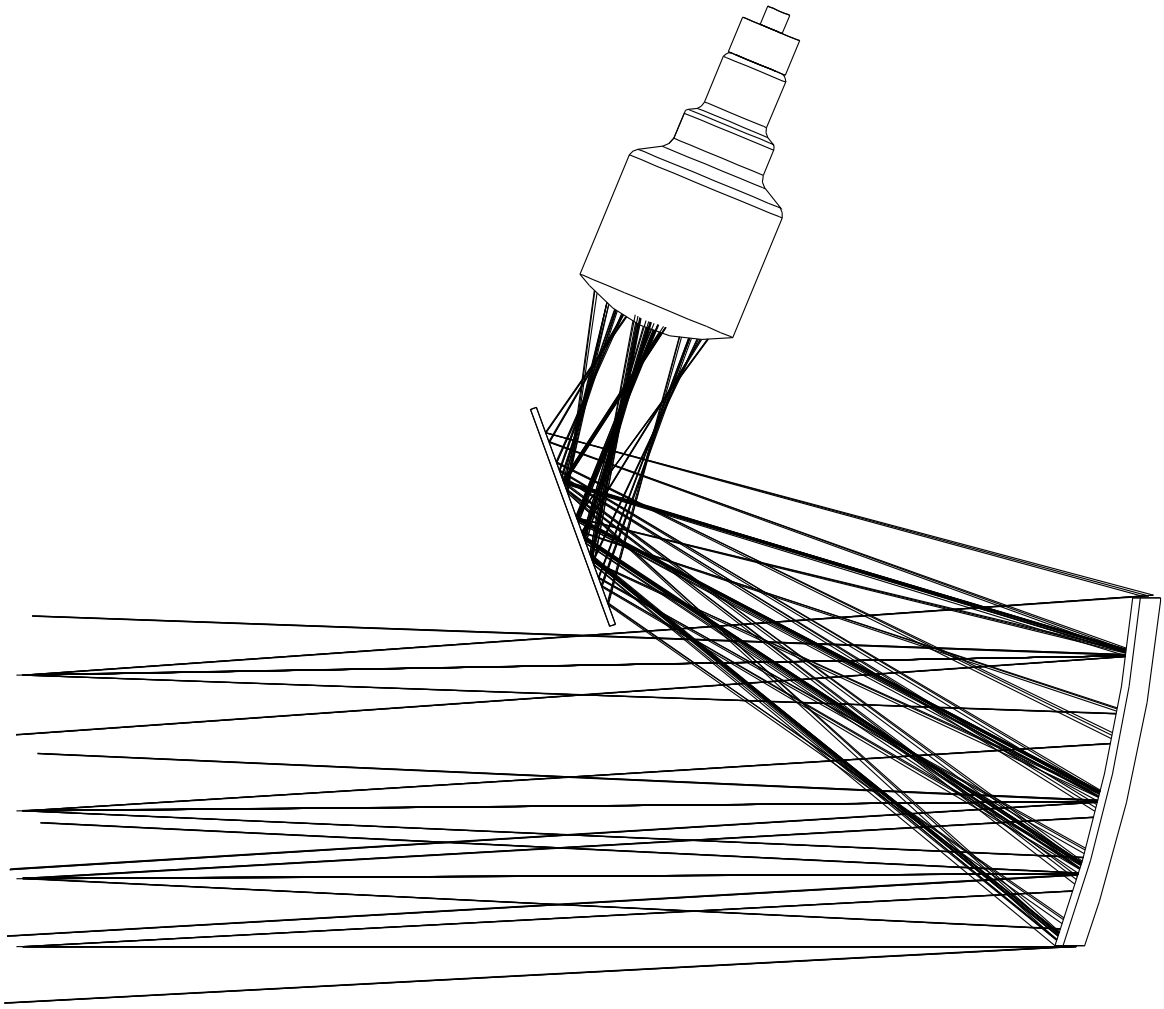

Figure 20: *All Cherenkov light, spherical and flat mirrors and photomultiplier.*

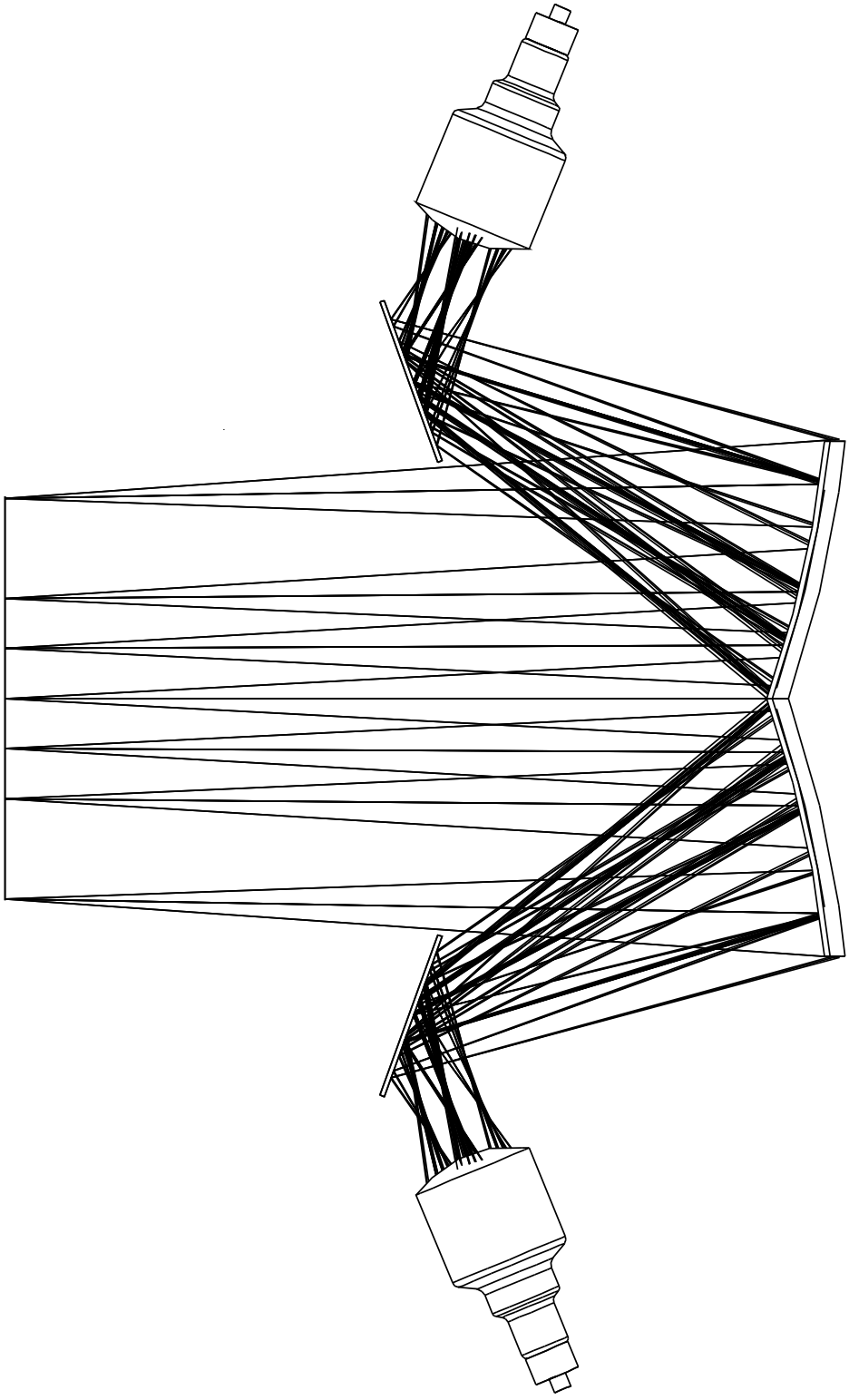

Figure 21: *Cherenkov light in C_4F_{10} detector. Direct light is shown only from the entrance window of the detector.*

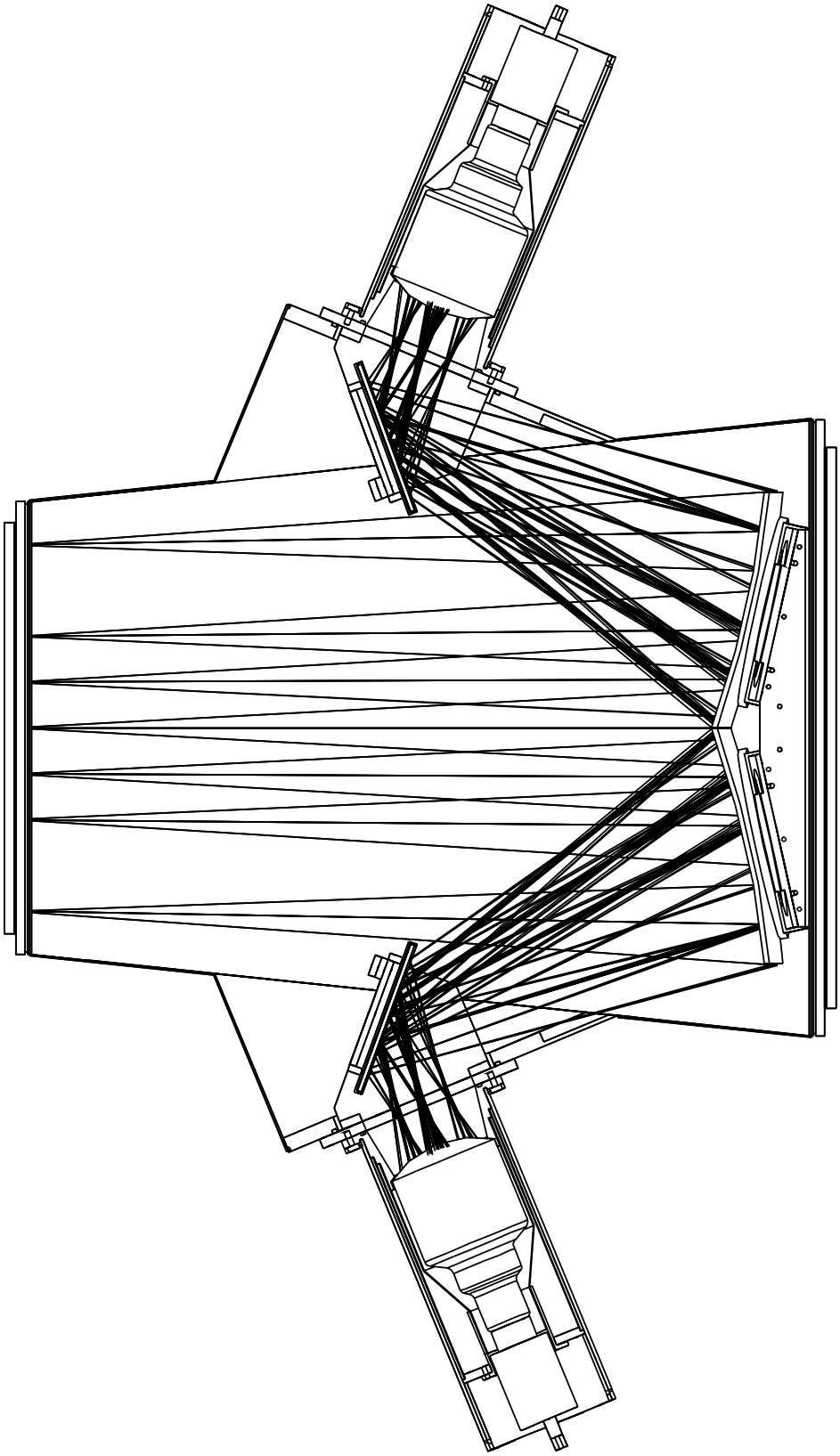

Figure 22: *Cherenkov light in C_4F_{10} detector. Direct light is shown only from the entrance window of the detector.*

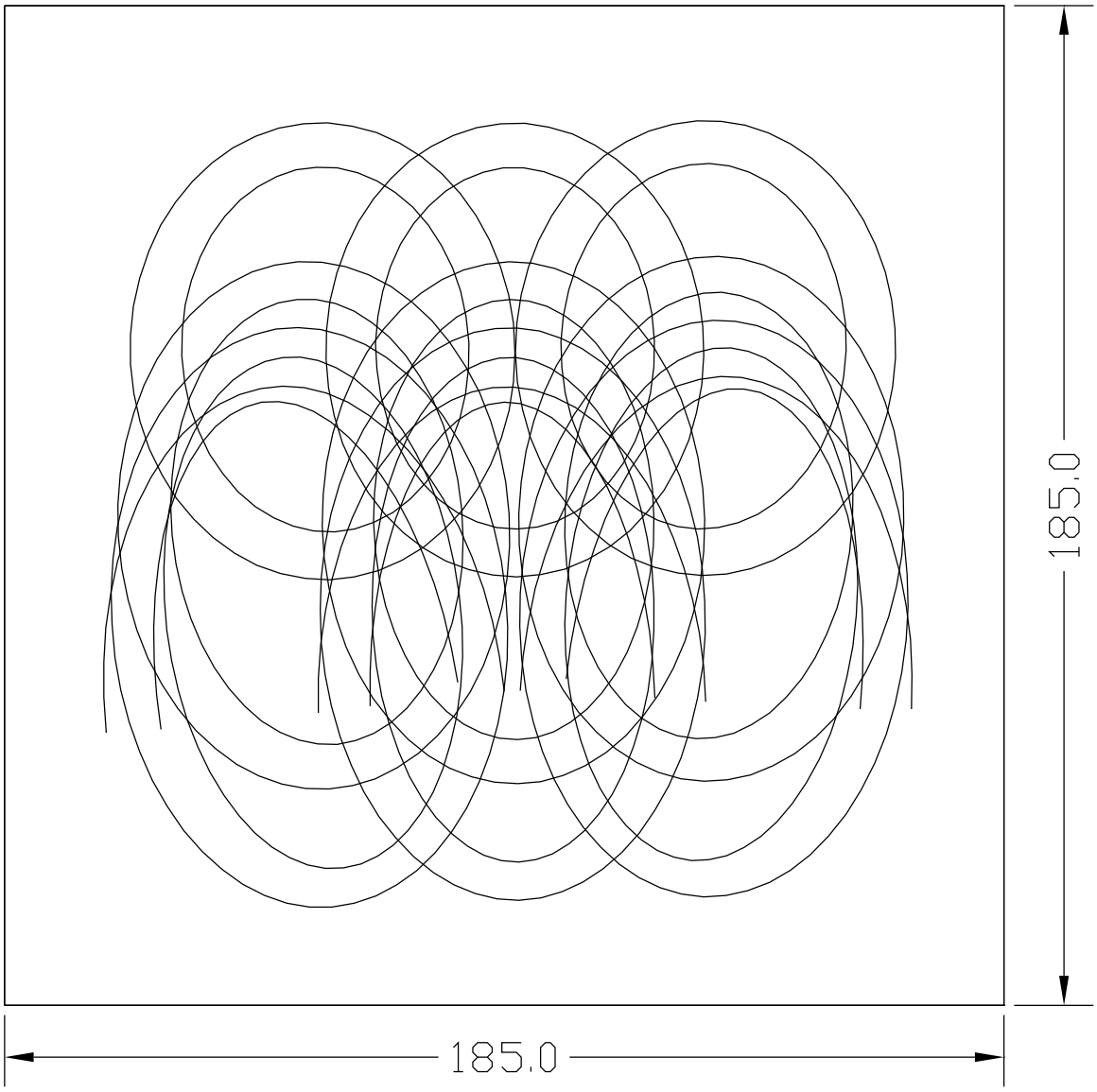

Figure 23: *Cherenkov rings on the flat mirror.*

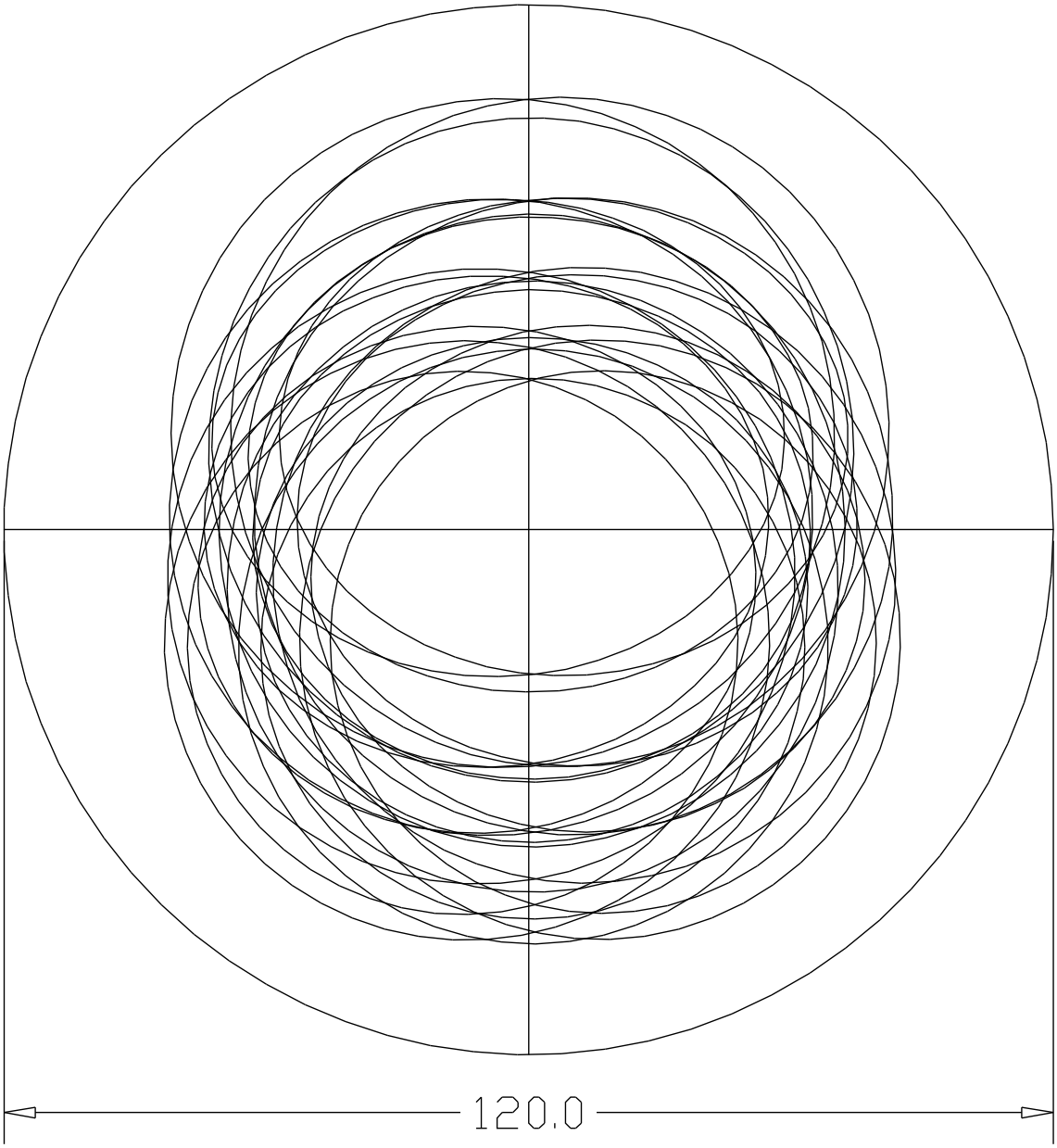

Figure 24: *Cherenkov rings on the PM photocatode.*

4 C_4F_{10} detector design

Side view of the detector with Cherenkov light is already shown in fig. 22.
Isometric views of the detector are in figs. 25, 26 and 27.
Dimensions of the detector are in figs. 28, 29 and 30.
Sperical mirrors and support are in figs. 31, 32 and 33. The big circular saddles (fig. 33) and the protector (fig. 31) allow to place the spherical mirrors precisely.
Flat mirrors and support are in fig. 34.
Photomultipliers HAMAMATSU H6528 are in figs. 35, 36 and 37.

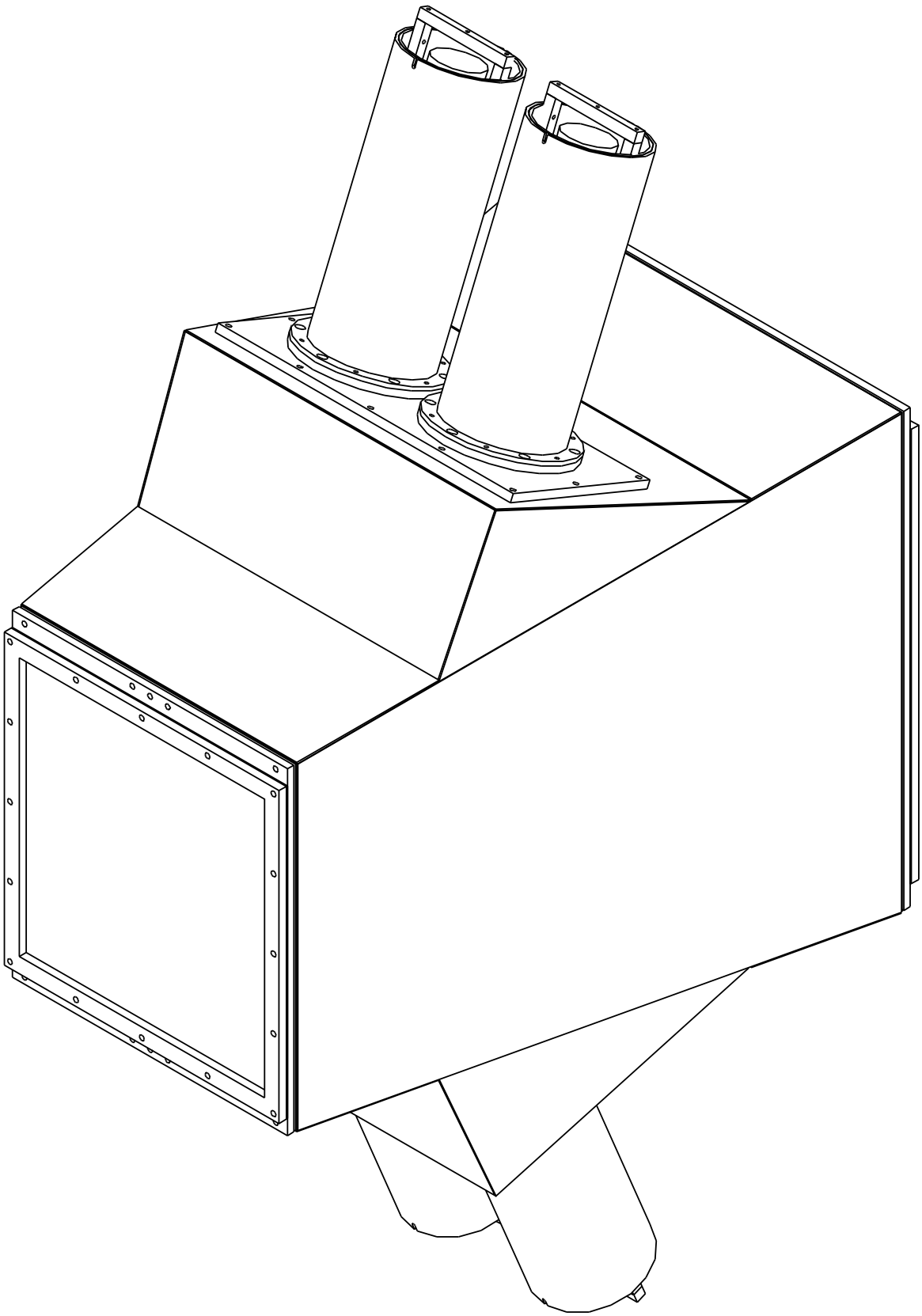

Figure 25: *Detector, isometric view.*

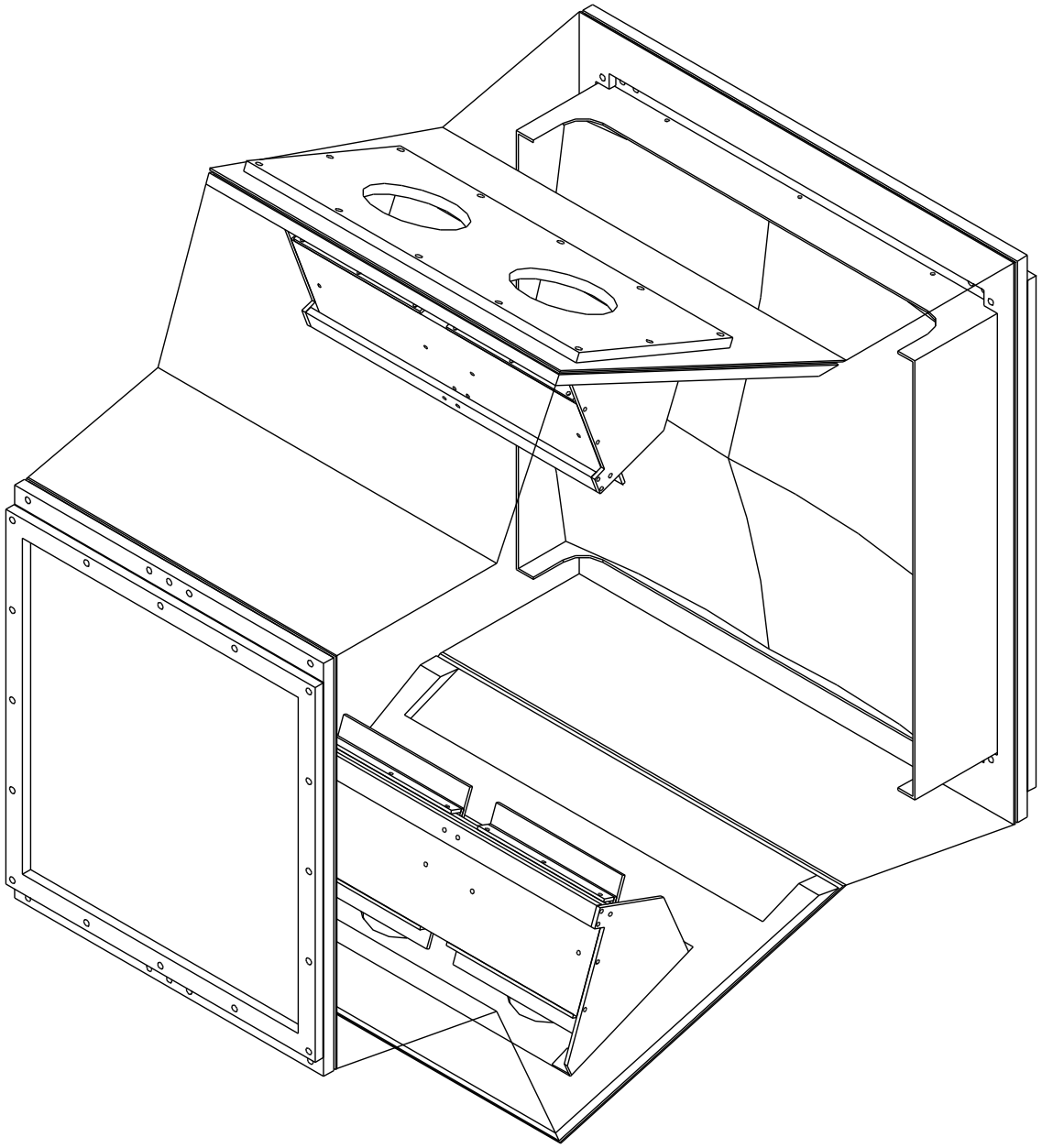

Figure 26: *Detector without PMs, isometric view.*

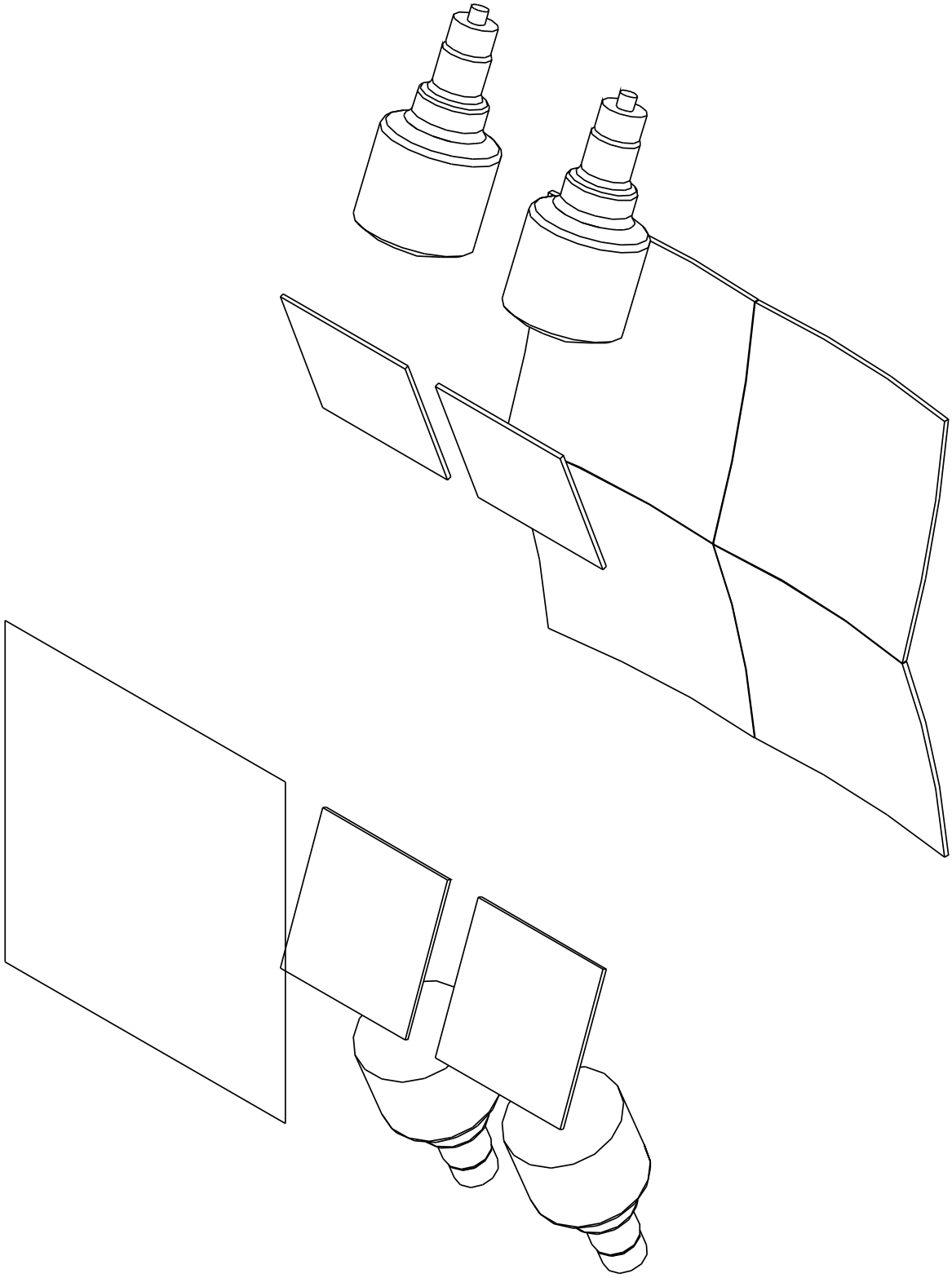

Figure 27: *Entrance window of the detector, spherical and flat mirrors and and PMs, isometric view.*

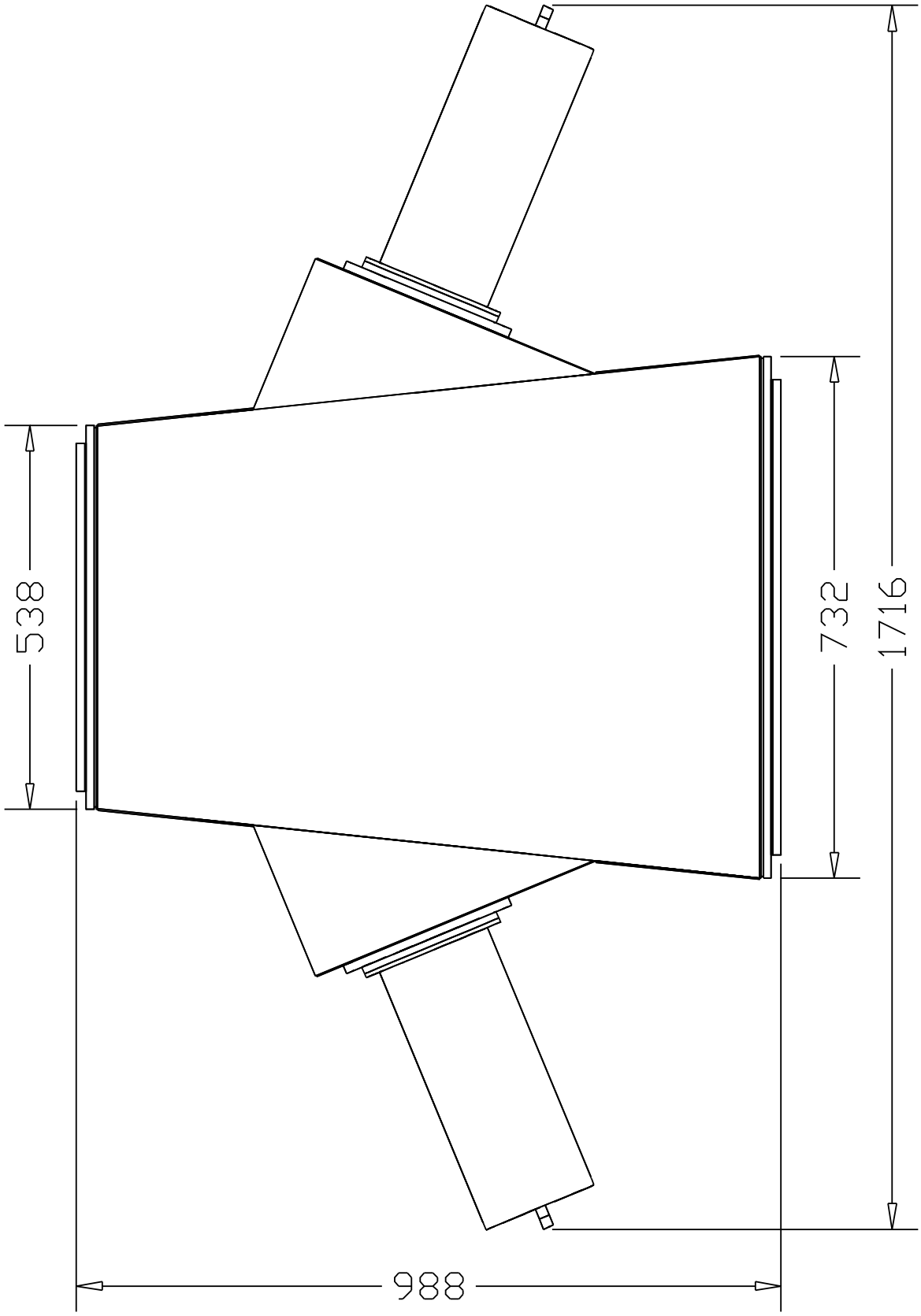

Figure 28: *Detector, side view, dimensions.*

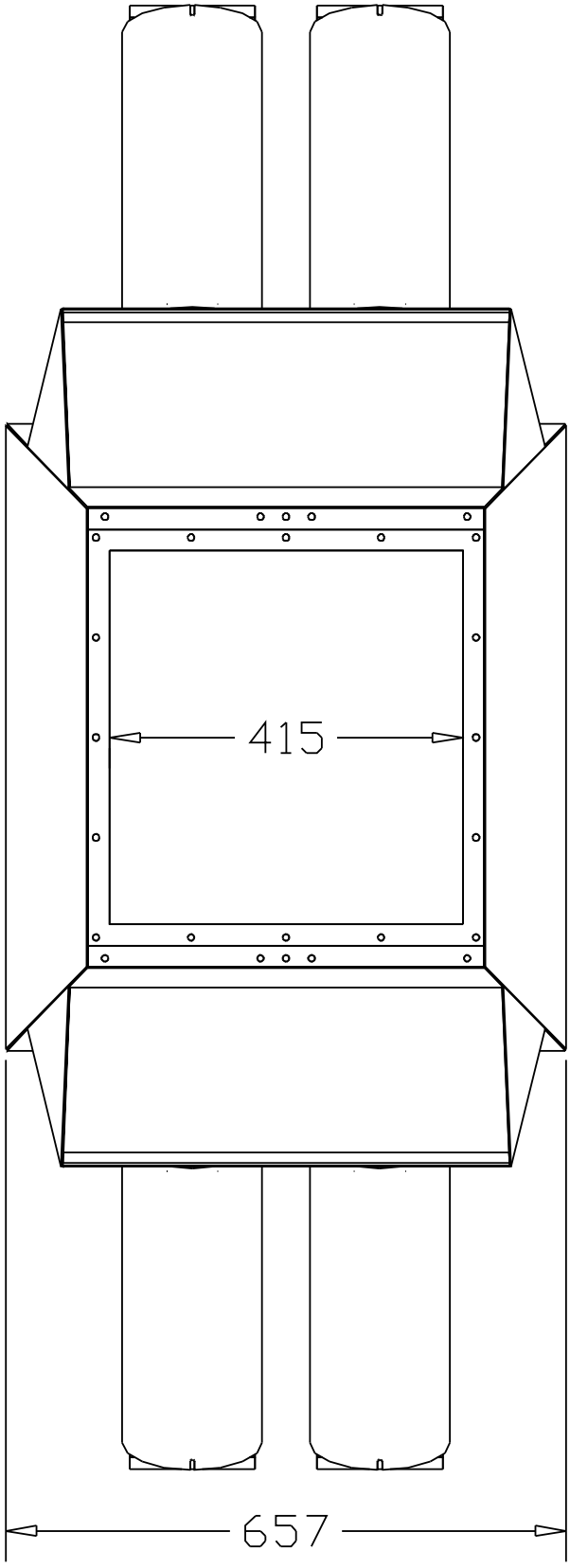

Figure 29: *Detector, front view, dimensions.*

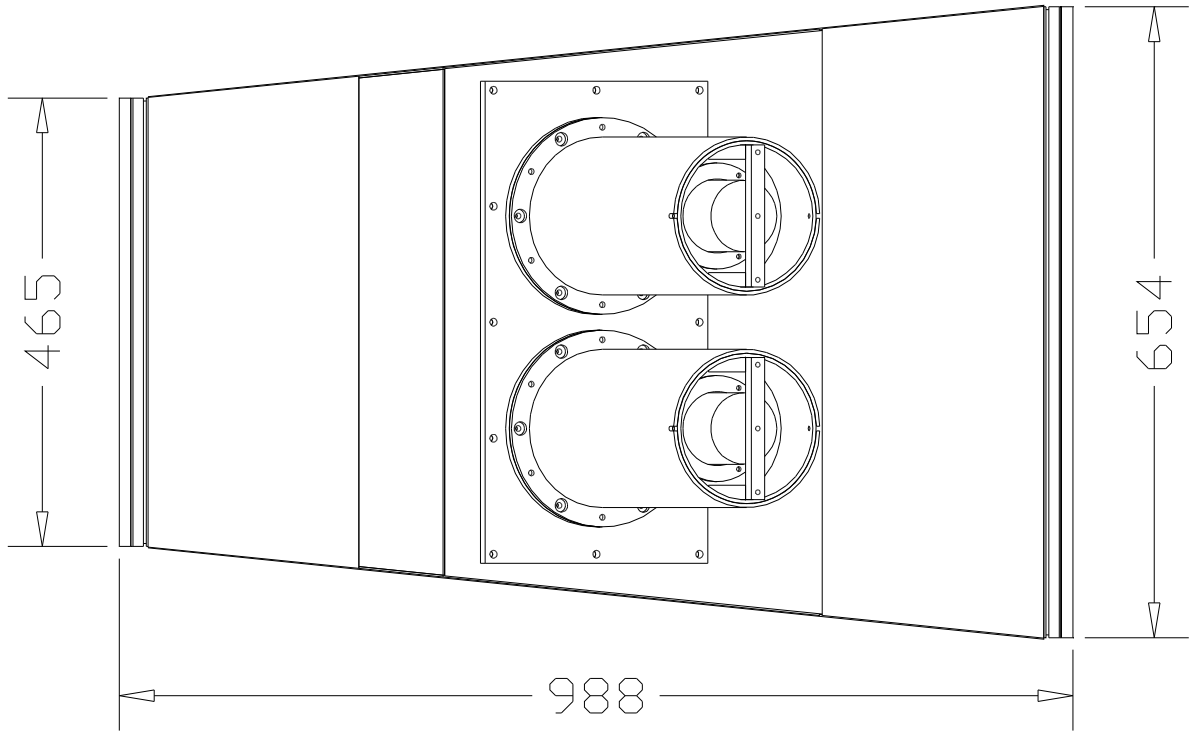

Figure 30: *Detector, top view, dimensions.*

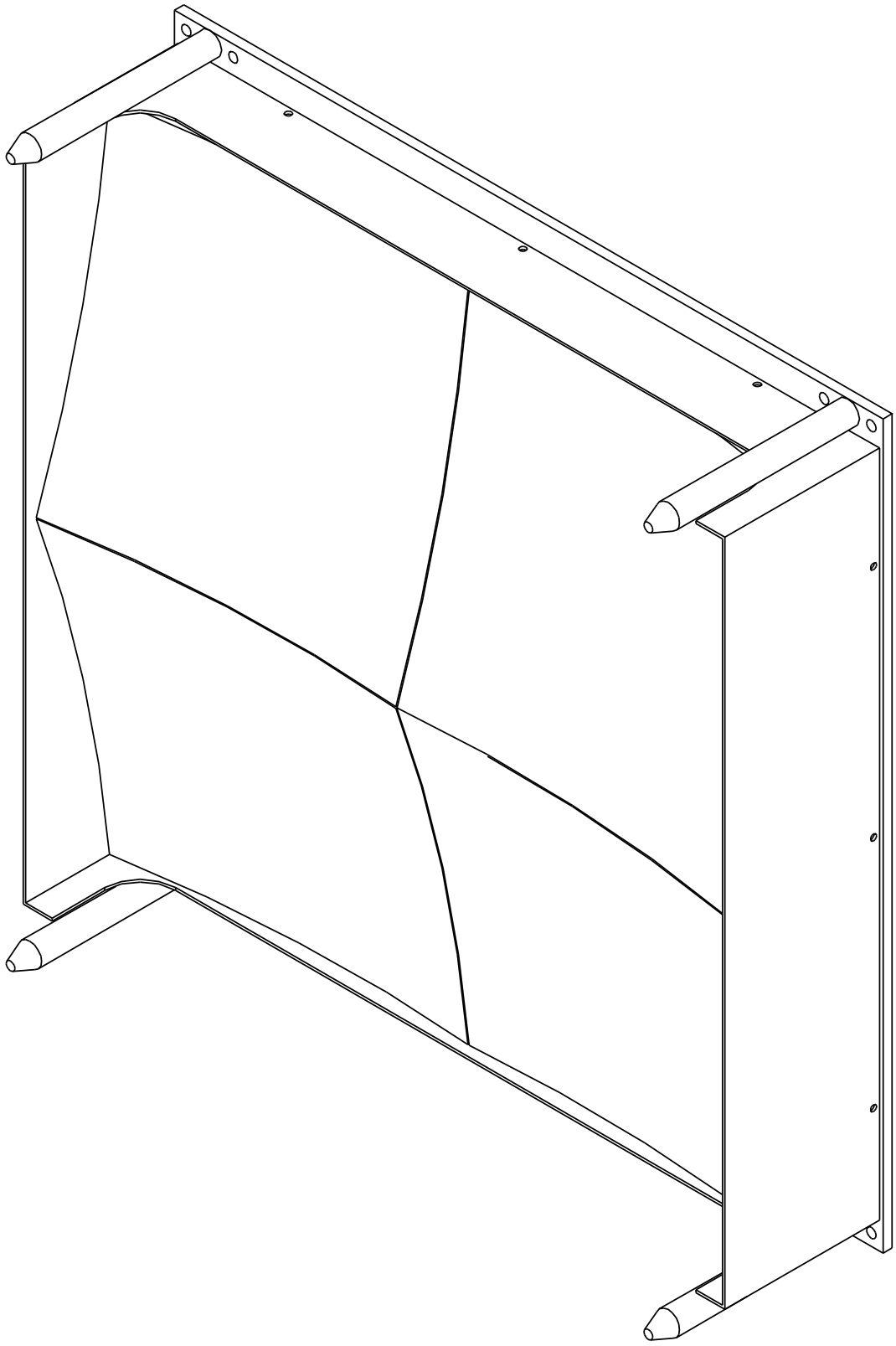

Figure 31: *Spherical mirrors, support, protector and giding rods.*

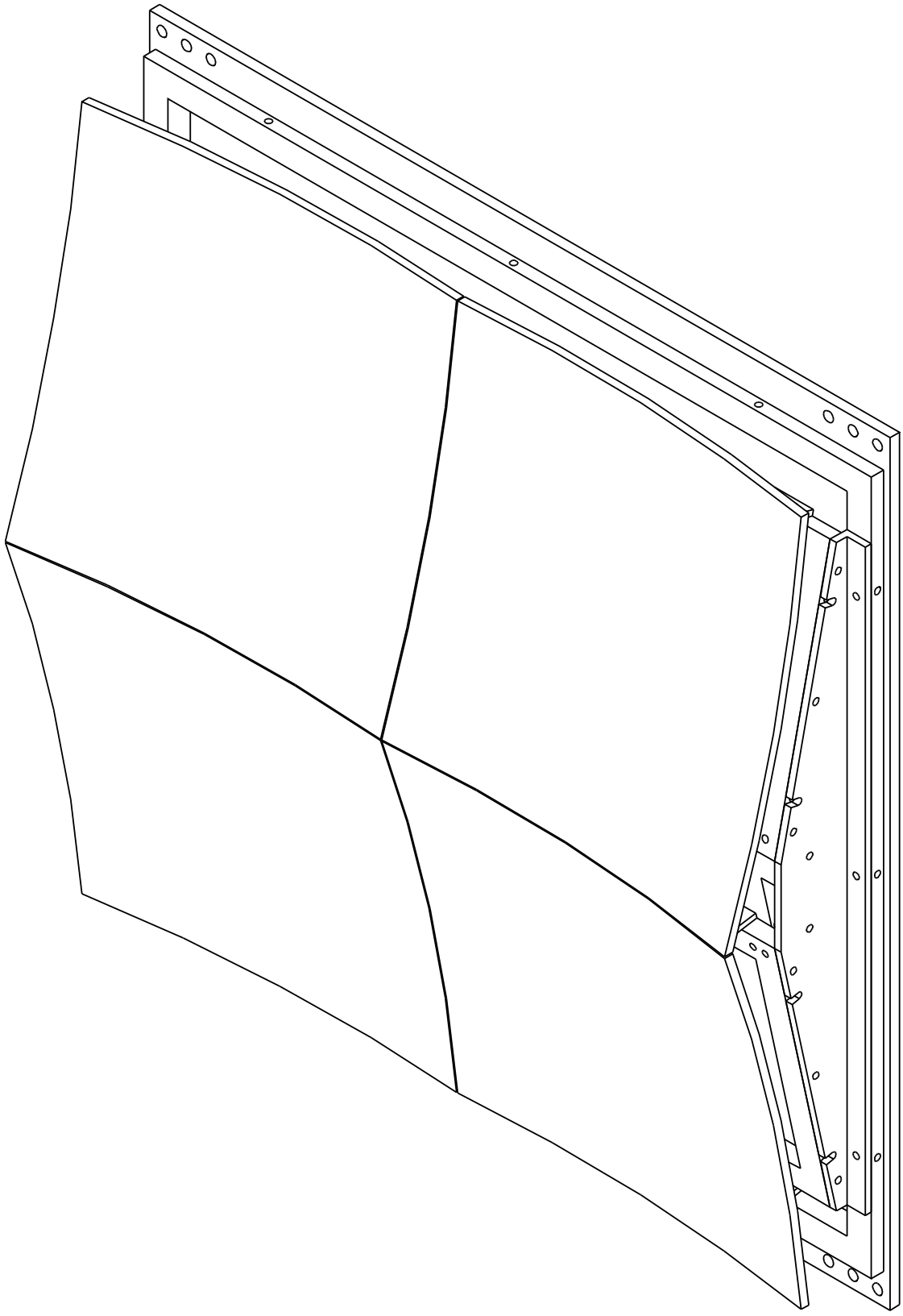

Figure 32: *Spherical mirrors and support.*

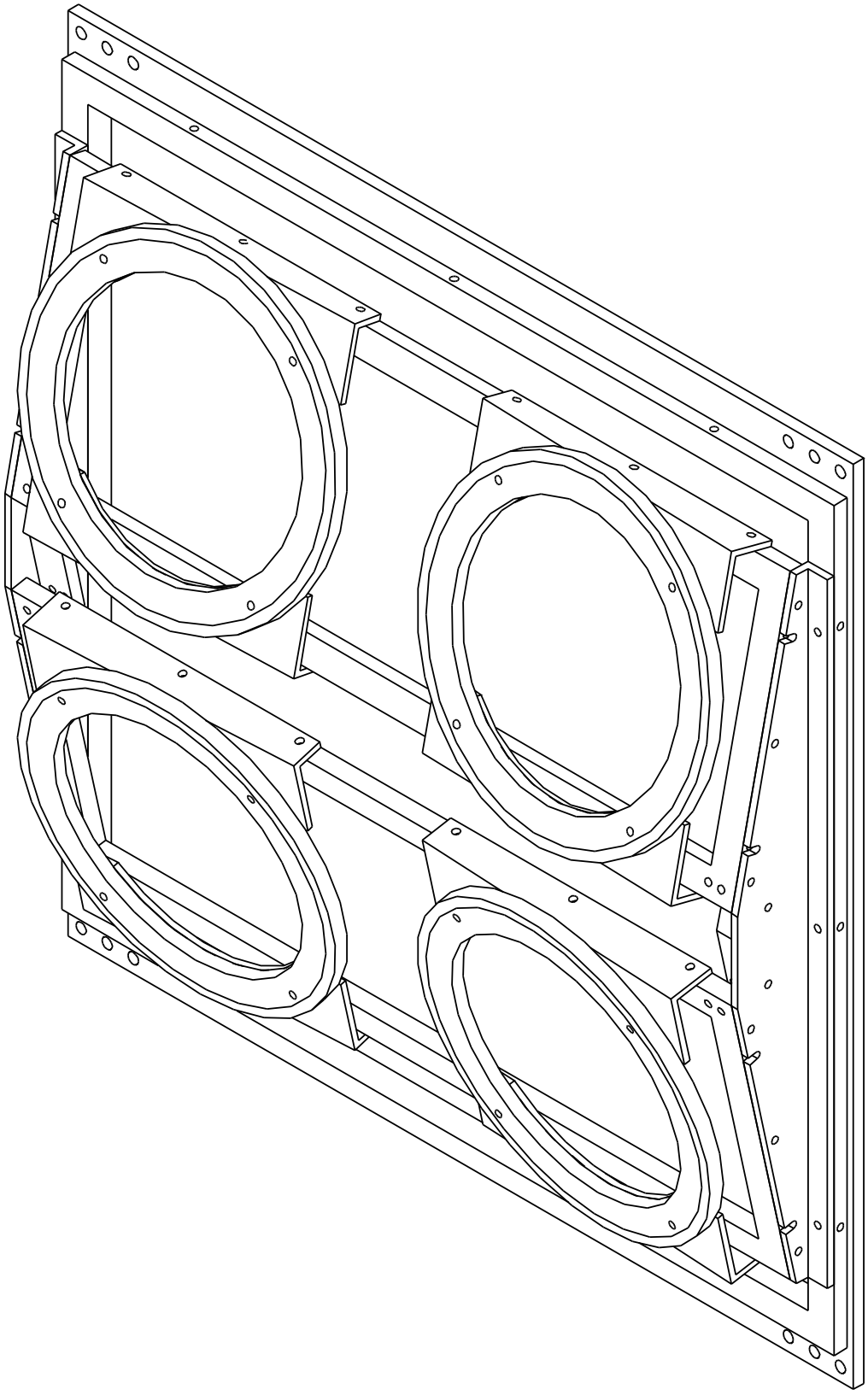

Figure 33: *Spherical mirror support.*

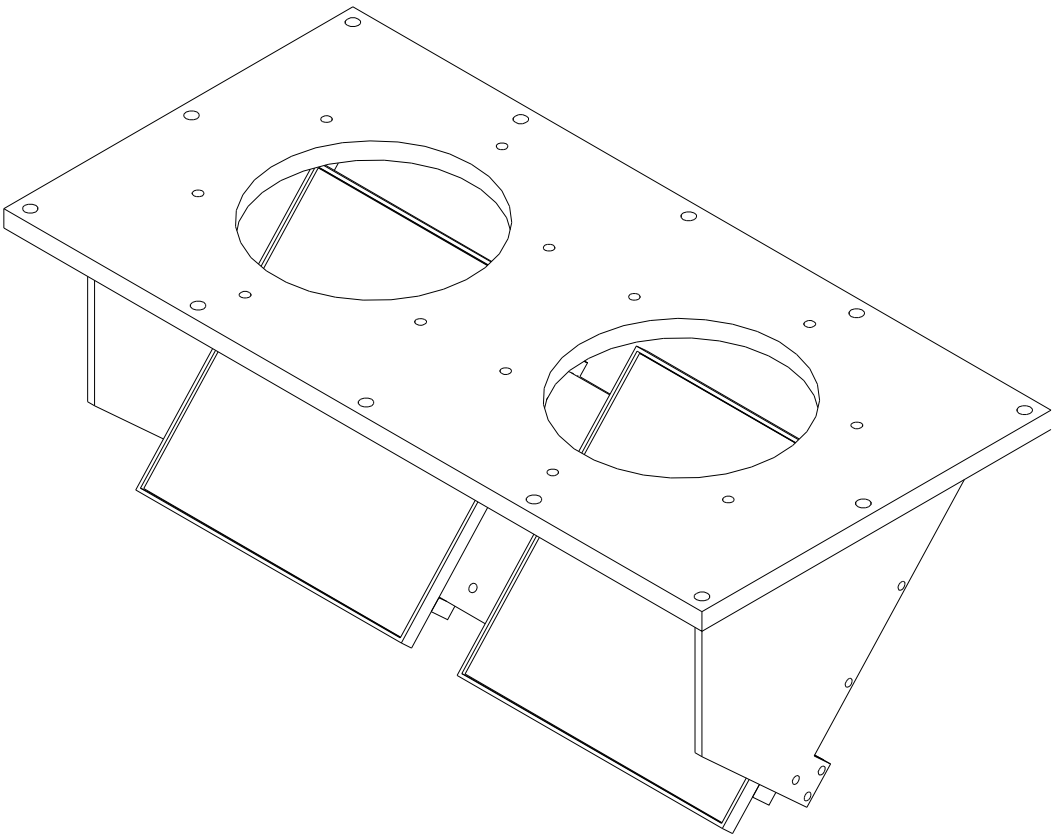

Figure 34: *Flat mirrors and support.*

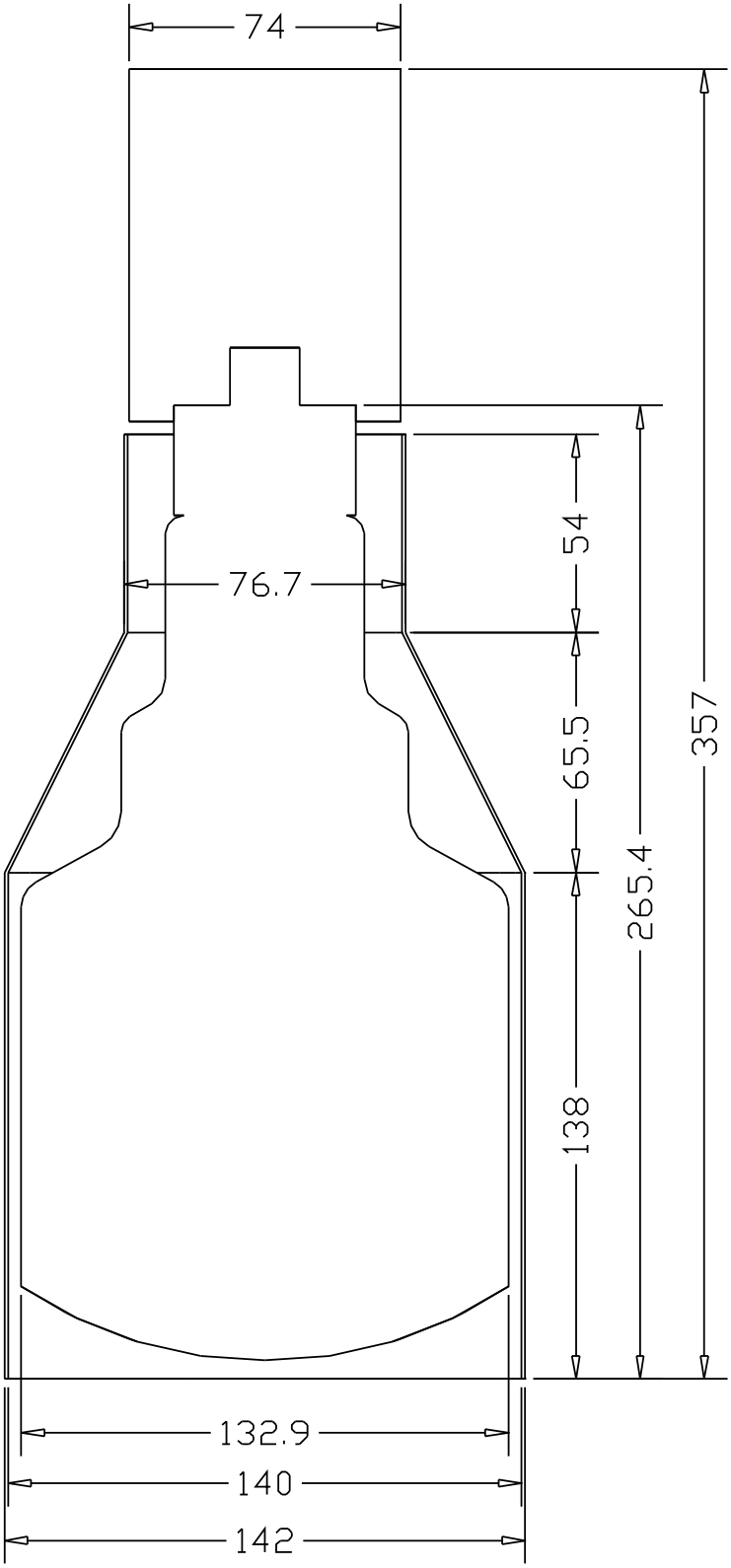

Figure 35: *HAMAMATSU H6528 photomultiplier with divider and μ-metal magnetic shield.*

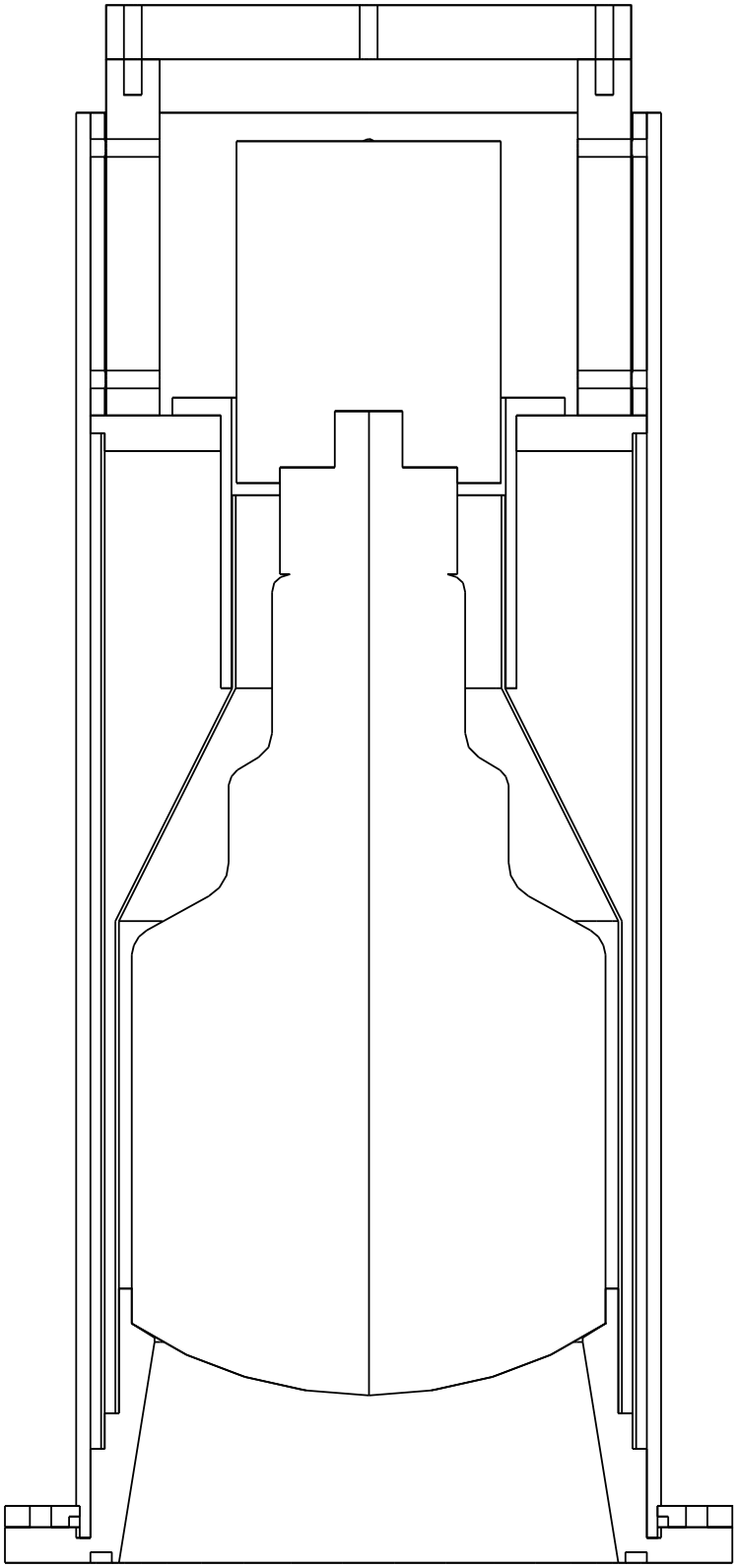

Figure 36: *Photomultiplier with divider, saddle and 3 layers of magnetic shield: 2 layers of μ-metal and 1 layer of steel.*

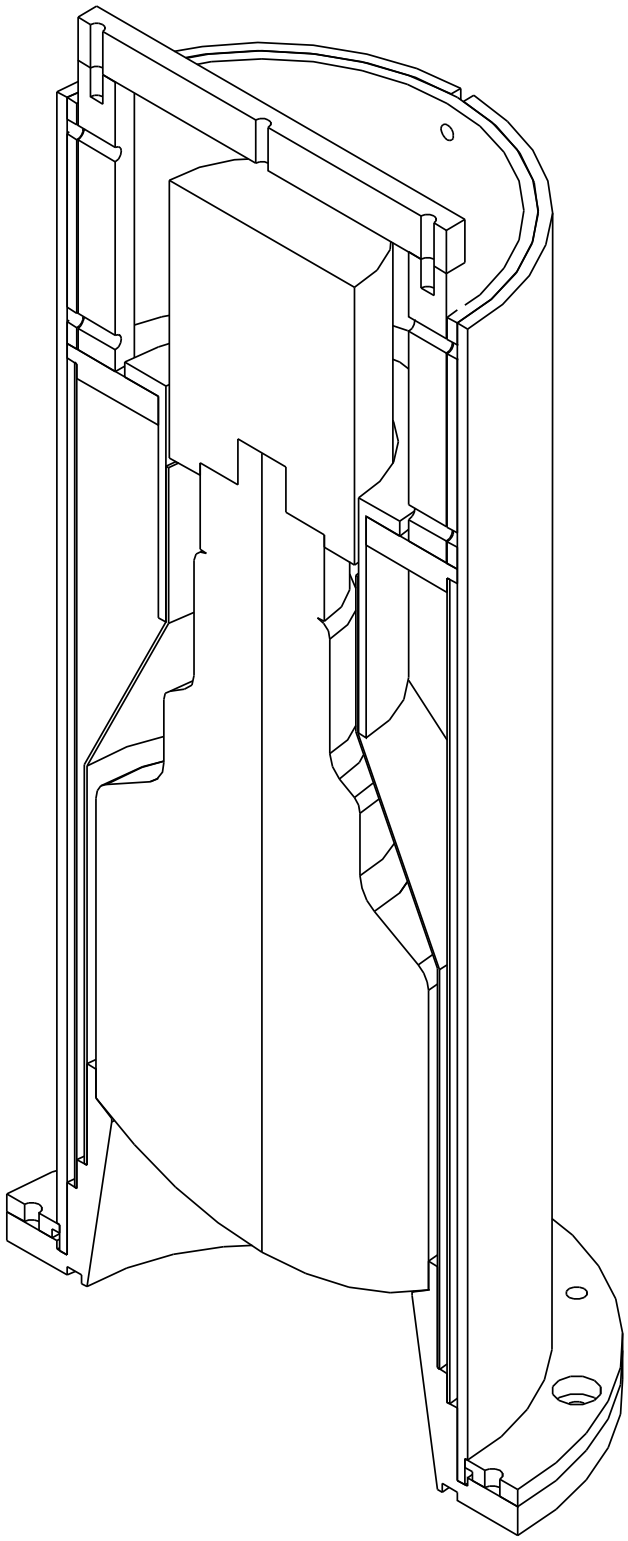

Figure 37: *Photomultiplier with divider, saddle and 3 layers of magnetic shield: 2 layers of μ-metal and 1 layer steel. Isometric view.*