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IMAGING OF THE VERTICAL PARTICLE TRACKS WITHOUT ANY DEPTH SCANNING

INTRODUCTION.

In up-to-date experiments on neutrino physics vertical particle tracks are detected in bilayer nuclear photoemulsion with central support [1, 2]. With such a system we obtain very high spatial and angular resolutions. However the depth of each layer is of the order of 50 μm, which is higher than the depth resolution, of the order of 3 μm, in high aperture optical microscope. So to construct a hole vertical particle track we must accomplish depth scanning and monitor the results obtained by means of sophisticated computer program.

The aim of earlier investigations in JINR [3, 4] was to detect selectively vertical particle tracks without any depth scanning operation. In the caustical meso-optical microscope [3] we may detect selectively Z-projection of vertical particle track onto the plane, perpendicular to Z-axis. The principle of this optical microscope is analogous to that of the classical confocal optical microscope [5]. It consists of two parts: illuminating system and imaging system. But in contrast to [5] we use cylindrical mesooptical condenser, which forms one-dimensional illuminating region in the form of narrow "fens" oriented parallel to the optical axis of the system. Scanning operation along depth coordinate is completely eliminated.

In this microscope the noise induced by light diffraction side-lobes has been suppressed [6]. Search and measurement algorithm for vertical particle track in the system [9] are based on the principle of reconstructed tomography. Beside some new variants of meso-optical condenser were proposed [7, 8].

In the paper [4] the principle of DArk-Field Scanning CONfocal (DAFISCON) microscope is described and the construction of such microscope built on the basis of 2D measurement microscope is presented. The result of experimental testing of DAFISCON microscope at high density of vertical particle tracks are given. The 2D plot and 1D plot of CCD dark field images are shown. Real spatial resolution of this microscope is defined by the aperture of the imaging microscope objective.

In this paper we explain the principle of new optical microscope which enable us to form the image of the whole vertical particle track without any depth scanning. Main parts of this new microscope are: meso-optical illuminating condenser, traditional imaging lens and a spatial image-transformer. The properties of such a system are explained and the longitudinal resolution is estimated.

IMAGING OF VERTICAL PARTICLE TRACKS
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In cylindrical coherent illumination system [4] we use first interference maximum of the internal caustic phenomenon produced by the traditional cylindrical lens (Fig. 1) with direct beam absorbed by the light stop S. The imaging lens L produces the said Z-projection of the vertical particle track as a shadow image with positive contrast.

The illuminating beam near the focus consists of the main focus region F and the system of internal interference maxima, first, second etc. (C_1, C_2 etc.) up to C_{16} (Fig. 2). Nuclear emulsion layer of the thickness 200 μm is located in the region of the first internal interference maximum C_1. Magnified regions F and C_1 are shown in Fig. 3 [4].

If vertical particle track is oriented at mall angle with respect to Z-axis of the microscope, then we have different Z-projections of different elements of the vertical particle track as shown in Fig. 4. The images of the points B, O, A of the inclined vertical particle track, that is the points B', O' and A' are located at different coordinates along Z-axis, if we use traditional microobjective L. To obviate the problem of depth focusing we use additional conical lens (CL) (Fig. 5) as a meso-optical element [8].

The combined system with a ring grating RG as an equivalent of a conical lens is shown in Fig.6. Here an image of each element of the inclined vertical particle track is a straight line segment, A_m', O_m' and B_m' of the point elements A, O and B of the inclined particle track. In this combined system we have a sharp Z-projection of the inclined particle track on the plane perpendicular to the optical axis of the system in the form of the segment A_m', Om', Bm'.

The Fig. 7 explains the problem of producing the real image of the vertical particle track using traditional objective L_1 attached to the nuclear emulsion layer via immersion prism Pr. The magnified image of our track is located on the focal plane which is inclined at very small angle with respect to the optical axis (Fig. 8). The ratio

$$\sin\beta_1/\sin\beta_2 \approx M, \qquad (1)$$

where M is the linear on-axis magnification of the imaging objective L. Due to this the light rays are going at very grazing angles with respect to the observation screen (photodetector).

Here we may use the Scheimpflug condition [10], which defines the construction of the light sectioning device with scanning mirror [11, 12]. For Triangulation angle 80° the total depth of field was equal t 1790

mm (!) for field of view 250 mm, the depth resolution and lateral resolution being equal to 30 μm and 170 μm respectively.
The principle scheme of our new microscope for imaging of vertical particle track without depth scanning is given in Fig. 9. To turn the light rays falling on the observation screen at very grazing angles we use spatial image transformer which consists of many (~300) mirror lamelar elements along the primary magnified image. In Fig. 9 only three mirror lamelar elements are shown. The reflected light rays are directed into the second imaging objective L_2 (Fig. 10). A Spatial image Transformer is shown in Fig. 7 as a system R which is not planar but has small convex sagging.

The saggital Δ (Fig. 11) appears as a result of the variation of the real linear magnification along the vertical particle track. For the linear segment of the length 0.58 mm using objective of the focal length 3.4 mm the length of the magnified image of the linear segment ACB will be equal to 48.8 mm. The transformed secondary image of the vertical particle track is detected by CCD shown in Fig. 7. The variation of the magnification factor along the primary image of the linear segment induces also the geometrical distortions in the secondary image as shown in Fig. 7. They can be corrected by the corresponding software program.

As the X-Y stage of the microscope is moving, the vertical particle track is falling into the illumination region and we se its image. Then this image disappears. The decay or scattering events are seen as a shorten image of the vertical particle track (Fig. 12). The non-illuminated region of the nuclear emulsion layer is shown as a dashed area. As a rule the secondary particle track of the decay or scattering event cannot be seen at all. The examples of three scattering or decay events are shown in Fig. 12 as SP_2, SP_5 and SP_6-images.

CONCLUSIONS

1. The proposed optical microscope for vertical particle tracks has no depth scanning operations.
2. The longitudinal resolution Δl is estimated as

$$\Delta l = 600\mu m / N_t, \qquad (2)$$

where N_t is the total number of silver grains in the particle track. For 25 grains/100 μm, emulsion thickness 600 μm we obtain Δl~4 μm. The lateral optical resolution is of the order of 1 μm.

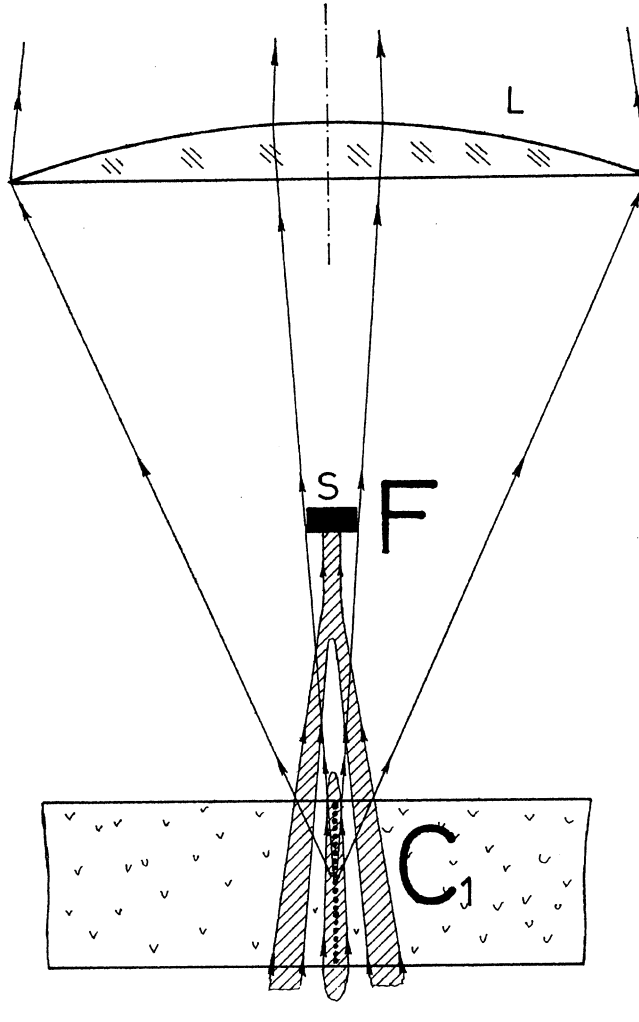

Fig. 1 Transfer cross section of the cylindrical coherent illumination system of the nuclear emulsion with vertical particle tracks: C_1 – first internal interference maximum over the total depth of the nuclear emulsion, F – focus region of the convergent light beam, S – light stop, L – imaging lens.

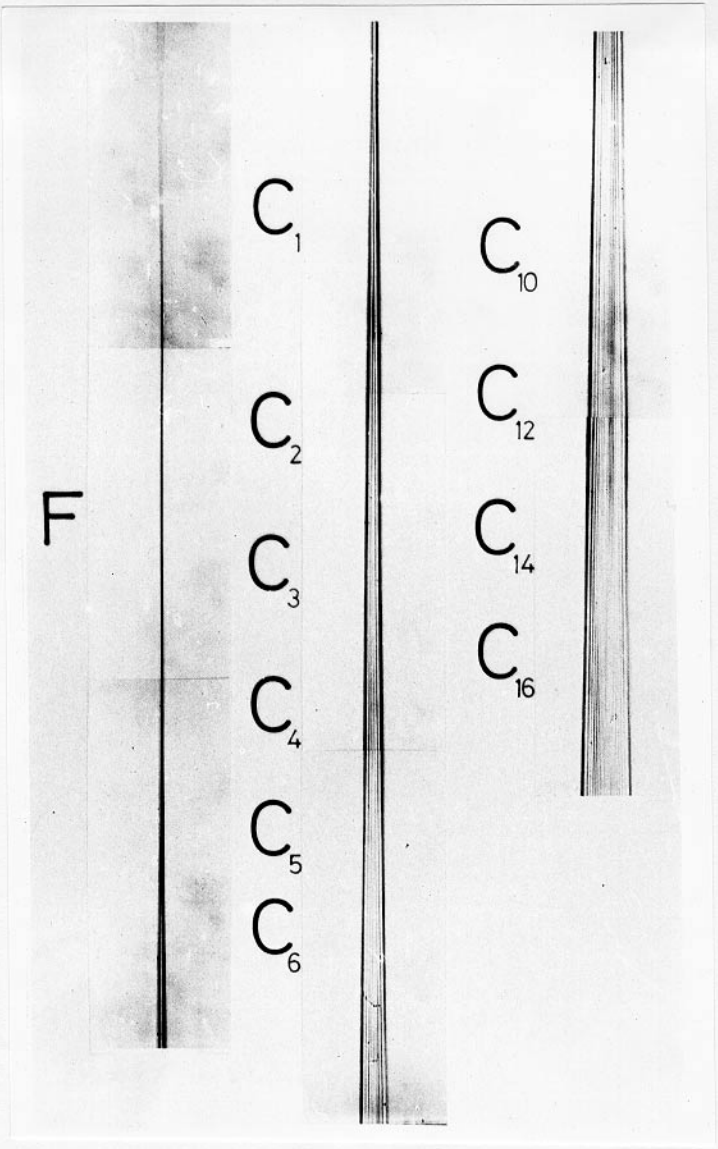

Fig. 2 Microscopic structure of the internal caustical pattern along the convergent light beam before the focus region F.

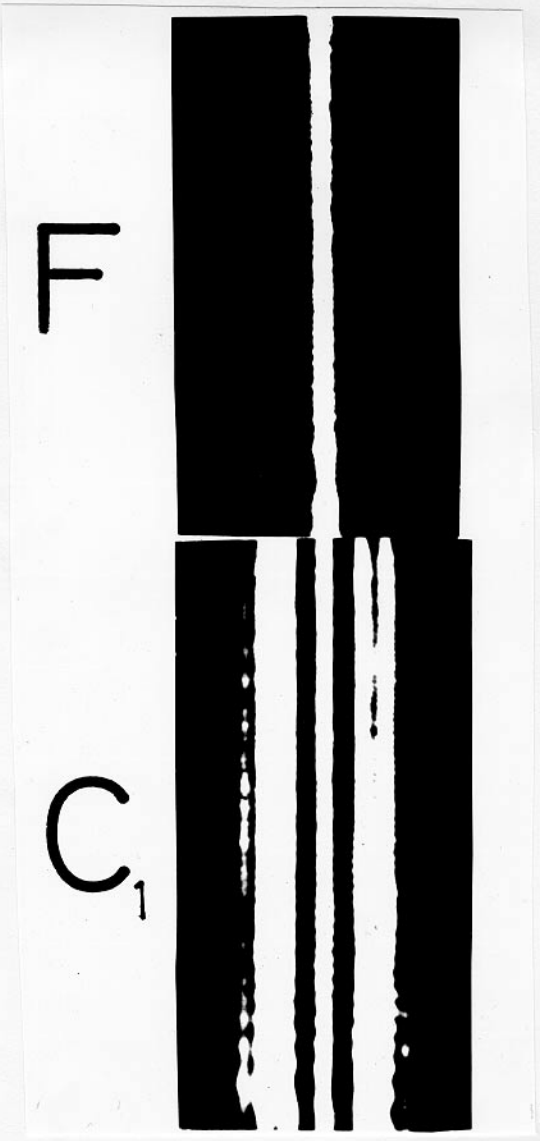

Fig. 3 The structure of the caustical pattern in F and in C_1 positions.

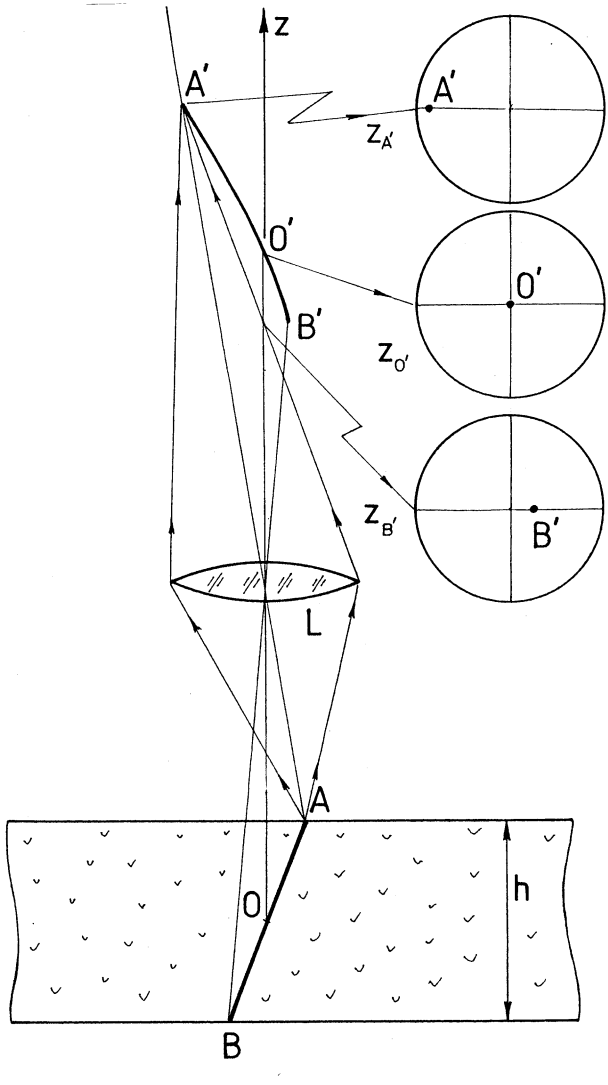

Fig.4 An image of vertical particle track which is oriented at small angle with respect to Z-axis of the microscope.

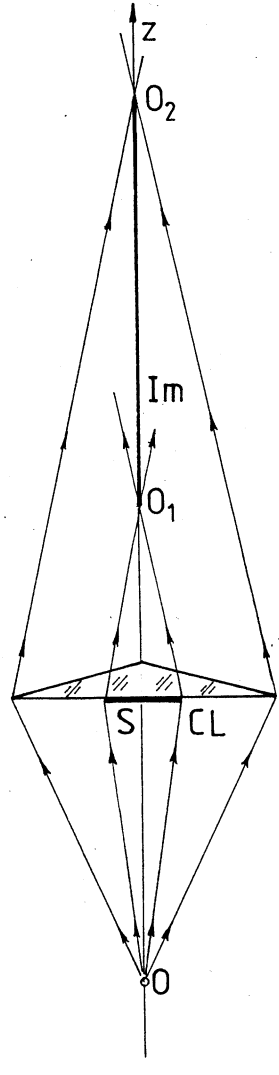

Fig. 5 Conical lens CL with light stop S which produces a longitudinal meso-optical image $O_1 \div O_2$ of the point object O.

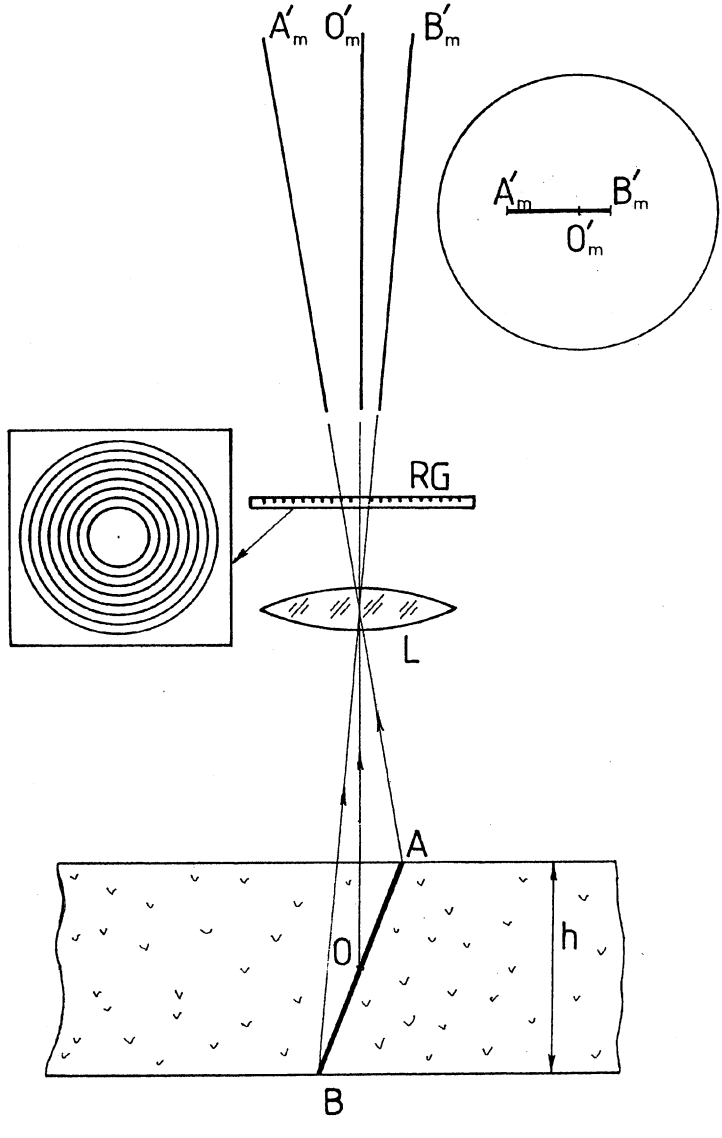

Fig. 6 The combined imaging system with lens L and ring grating RG. Each point of the vertical particle track BOA is imaged into the line segment such as A_m and others. At the screen oriented perpendicularly to the optical axis we see the meso-optical image $A_m'O_m'B_m'$ of the whole vertical particle track BOA.

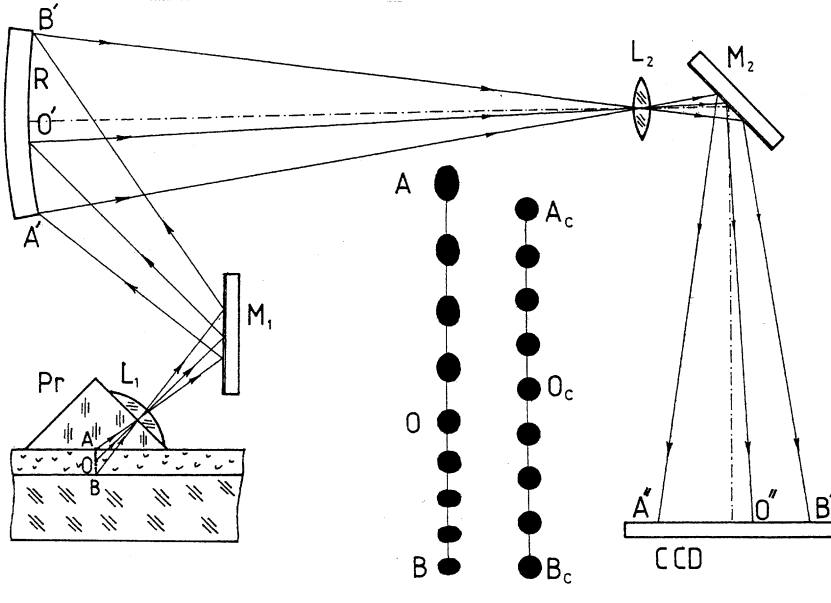

Fig. 7 To produce the image of any vertical particle track we must take a side view by means of the immersion prism Pr.

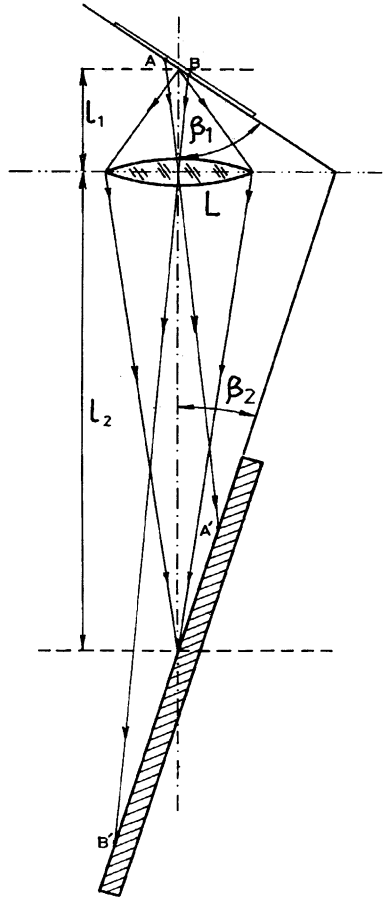

Fig. 8 Position of the magnified image of the vertical particle track in the system show in Fig. 7 (Scheimpflug condition [10]).

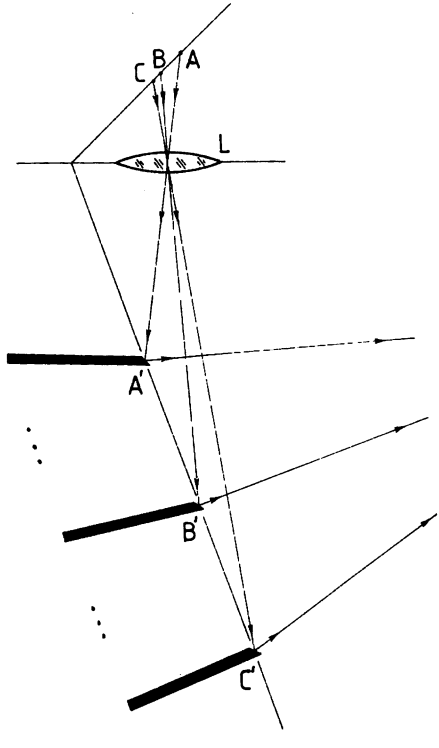

Fig.9 The principal construction of the spatial transformer of our new microscope for imaging of the vertical particle tracks without depth scanning. Only three mirror lamelar elements are shown.

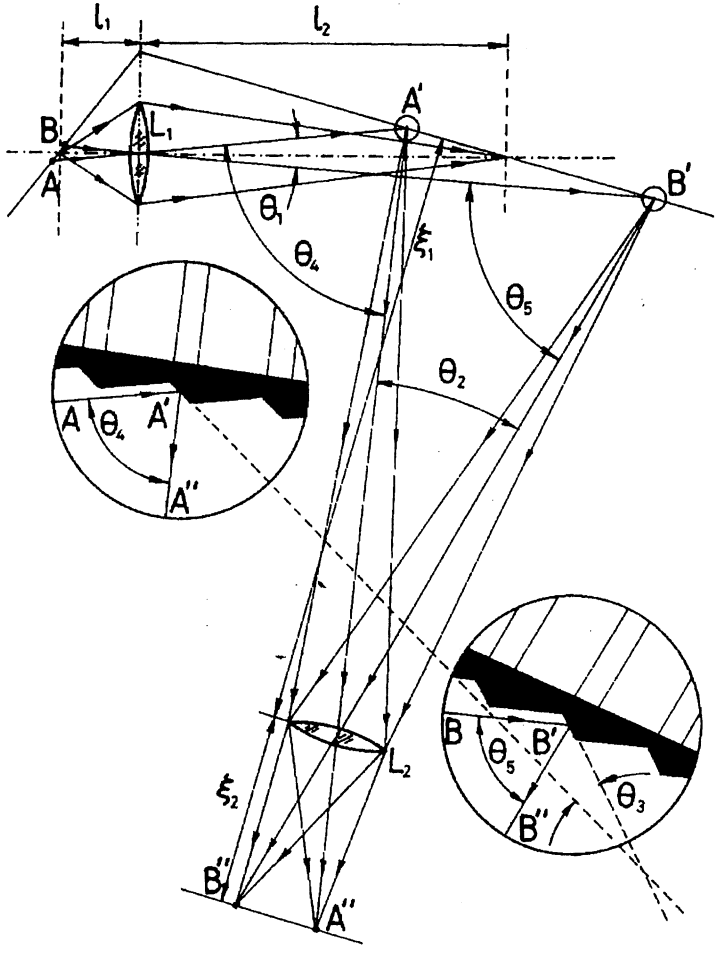

Fig. 10 The complete scheme of our microscope: BA – vertical particle track, L_1 – the first imaging lens, A'B' – primary image, where the spatial transformer of many mirror lamelar elements is located, L_2 – the second imaging lens, B"A" – final image of whole vertical particle track.

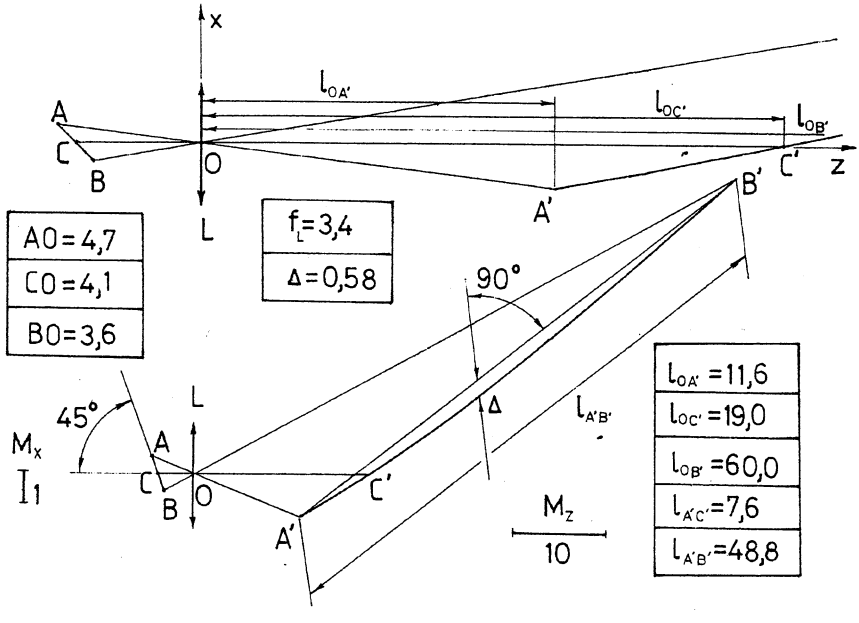

Fig. 11 The origin of the sagitta Δ in the primary image of the vertical particle track A'C'B': f_l – focal length of the imaging lens L. The drawing shown in bottom has horizontal scale 10:1 with respect to the vertical scale. For f_l = 3.4 mm the sagitta Δ= 0.58 mm, and $l_{A'B'}$ = 48,8 mm.

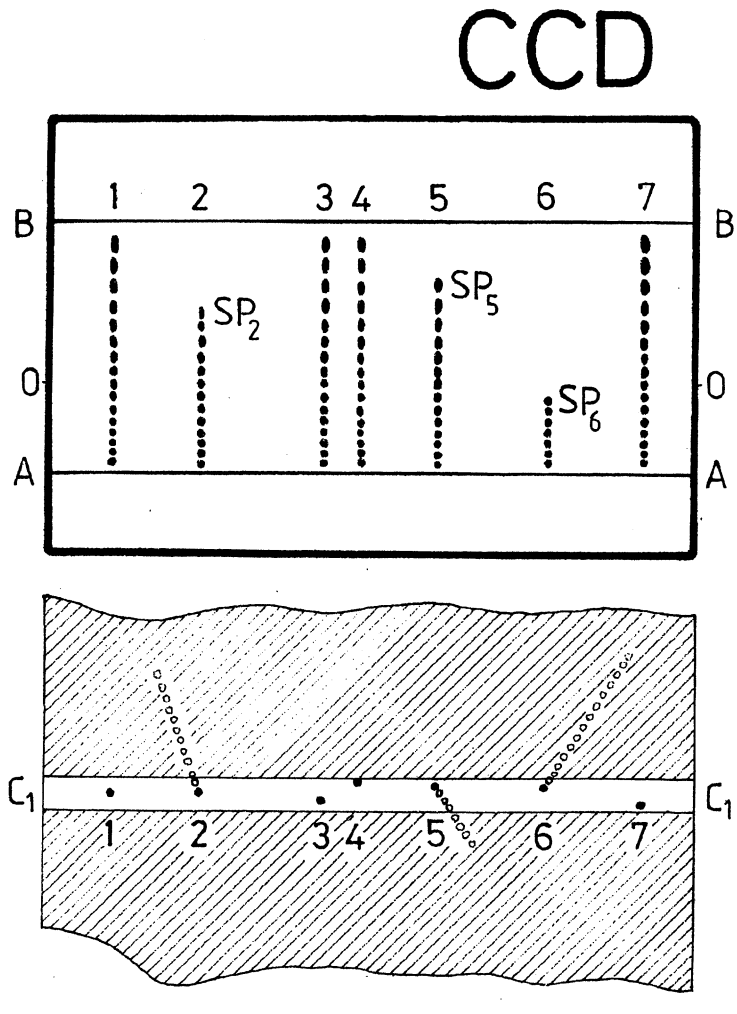

Fig. 12 The view of the secondary image of seven vertical particle tracks, three of which are decay or scattering events (SP_2, SP_5 and SP_6). At the bottom, the positions of these seven particle tracks with respect to the illuminating "fens" C_1 –C_1 are shown.

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Получение изображений вертикальных следов частиц
без какого-либо сканирования по глубине

Изложен принцип действия нового оптического микроскопа, который позволяет получать изображение вертикального следа частицы без какого-либо сканирования по глубине. Этот новый оптический микроскоп содержит пространственный преобразователь, который состоит из зеркальных ламеллярных элементов и который образует вторичное в фокусе изображение вертикального следа частицы. Приведены свойства такой системы. Сделана оценка разрешающей способности.

Работа выполнена в Лаборатории ядерных проблем им. В.П.Джелепова ОИЯИ.

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Imaging of the Vertical Particle Tracks
without Any Depth Scanning

The principle of the new optical microscope which enables us to get the image of the vertical particle track without any depth scanning is described. This new optical microscope contains a spatial transformer which consists of mirror lamelar elements and which produces a secondary in focus image of the vertical particle track. Properties of such a system are presented. A longitudinal resolution is estimated.

The investigation has been performed at the Dzhelepov Laboratory of Nuclear Problems, JINR.

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