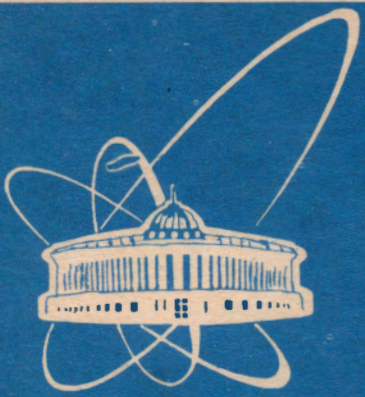

СООБЩЕНИЯ
ОБЪЕДИНЕННОГО
ИНСТИТУТА
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MESO-OPTICAL MICROSCOPE OF HIGH PRODUCTIVITY FOR VERTICAL PARTICLE TRACKS.

Proposal

1995

1 INTRODUCTION

Several scientific international collaborations have been organized to search for such rare effects as $\nu_\mu - \nu_\tau$ oscillations [1] and to investigate Pb–Pb interactions [2]. To locate the secondary particles in these events with high spatial resolution, additional blocks with double sheets nuclear photoemulsion layers on plastic substrate have been used [3]. To observe the vertical particle tracks in these double sheets layers, a computer assisted optical microscope was used [4]. The scanning of the nuclear photoemulsion layer in such a microscope is accomplished according to the point-by-point algorithm over the 3D volume. It is clear that such point-by-point scanning algorithm when applied to objects such as straight line particle tracks is very unadequate and extremely slow indeed.

In this paper the principle of the new meso-optical microscope proposed by the author and designed for selective observation of the vertical particle tracks in the nuclear photoemulsion is explained. Some new illuminating systems used in the proposed meso-optical confocal microscope are presented. The results of the experiments performed on various setups which are equivalent to the proposed microscope are given. The proposed new meso-optical confocal microscopes for selective observation of the vertical particle tracks can be effectively used in the experimental investigation of the neutrino oscillations.

The construction of the first meso-optical microscope designed for observation of the vertical particle tracks was explained in [5]. The scanning along Z-coordinate is absent in this meso-optical microscope. In the other system [6] the output efficiency of the search was increased due to the new observation algorithm with scanning accomplished simultaneously over ~ 100 fields of view.

To suppress the effect of the diffraction side-lobes on the signal-to-noise ratio, a confocal meso-optical microscope was proposed [7]. In this microscope the observations of the vertical particle tracks are made by means of the meso-optical condenser which produces an illuminated region having narrow "fens" shape. This "fens" is oriented parallel to the optical axis of the system. The search and measurement algorithm in the system [8] are based on the principle of the reconstructed tomography [9]. The output efficiency of such meso-optical microscope for selective observation of the vertical particle tracks is $10^2 \div 10^4$ times higher than in the traditional optical microscopes.

The proposed meso-optical microscopes for selective observation of the vertical particle tracks can be used in the experimental investigation of the neutrino oscilla-

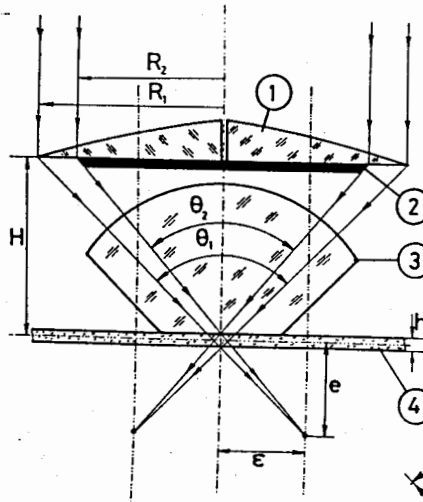


Fig. 1. Meso-optical condenser with immersion lens: 1 — cylindrical half-lens, 2 — central stop, 3 — immersion lens with enter surface perpendicular to the incoming light rays, 4 — nuclear emulsion layer, ε — transversal eccentricity of the half-henses, (H + e) — its focal length.

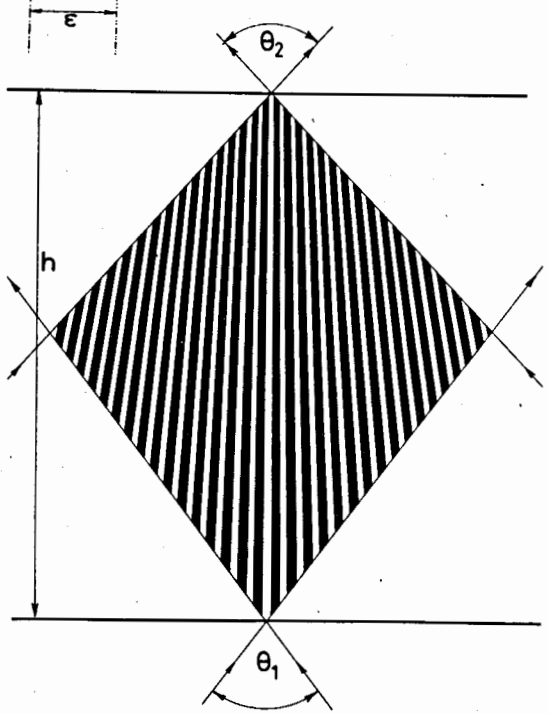


Fig. 2. Microscopic pattern of the interference picture produced by two restricted convergent cylindrical waves: θ_1 and θ_2 are the angles between two wavevectors at the upper and at the bottom surfaces of the nuclear emulsion layer, respectively.

tions. The aim of these experiments is to detect in the nuclear photoemulsion very rare decay of the τ-lepton produced by the interaction of the τ-neutrino $\nu_\tau N \to \tau^- X$.

The first such experiment has been performed in 1979 [10] at Fermilab by using the nuclear photoemulsion technique for detection of the τ-lepton decay. The second experiment with nuclear photoemulsion target of 30 l was made in 1986 [3]. The forth-coming experiment with nuclear photoemulsion target of 200 l (800 kg) was proposed in 1990. The exposure time needed in this experiment is up to 2 years. The confocal meso-optical microscopes for selective observation of the vertical particle tracks proposed in this paper may be very effective in these experiments.

2 NEW ILLUMINATED REGION

To ameliorate the signal-to-noise ratio in the earlier meso-optical illuminated region, some new variants of the meso-optical condenser [5] were proposed in [8,11]. In the illuminated system with two convergent cylindrical waves, shown in Fig. 1, the direct light beams are absorbed in its focal plane by the stop 2. To suppress the parasite reflected light rays from the interface surfaces, a cylindrical immersion lens 3 has been used. This system is provided with two cylindrical half-lenses 1 with their optical axes shifted at the distances $\pm\varepsilon$ with respect to the symmetry axis of the whole system. The stop 2 restricts the internal parts of the incoming light rays.

The main feature of the illuminated region produced by such a device (Fig. 2) is that the period of the interference fringes is changing along Z-axis.

The construction of the proposed device with convergent illuminating light beams is presented in Fig. 3. The first cylindrical lens 1 produces a long range focusing of the input light beam in the vertical plane. The second cylindrical lens 2 focuses the input light beam in the horizontal plane. The narrow bright segment is transmitted through the 1D pinhole 3. A pair of two eccentrically located cylindrical half-lenses 5, provided with stop 4, generates two mutually crossed convergent cylindrical waves which give rise to the complex interference picture inside the nuclear emulsion layer 6. Two 1D stops 7 absorb the direct light beams. The cylindrical lens 8 focuses the light, diffracted on the vertical particle tracks, onto the photodetector 9.

3 CONFOCAL SYSTEM

In the device provided with two cylindrical convergent light beams (Fig. 3), the diffracted light is picked up by the cylindrical lens 8 and is focused onto the point-like photodetector 9. The spatial dimension of this photodetector is much more narrow than the transfer dimensions of the vertical particle track in the nuclear photoemulsion layer 6. To increase the signal-to-noise ratio, another system must be adopted [5,10-12], namely, to use the principle of the confocal microscope. The coherent transfer function of such a confocal microscope is equal to the product of the corresponding

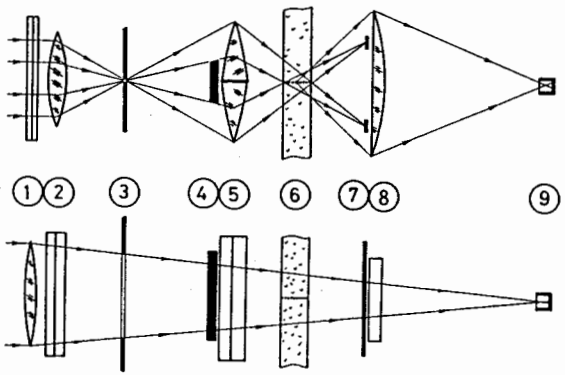


Fig. 3. Microscope for selective observation of the vertical particle tracks with convergent cylindrical illuminating light beams: 1 — first cylindrical lens, 2 — second cylindrical lens, 3 — 1D pinhole, 4 — stop, 5 — cylindrical half-lenses, 6 — nuclear emulsion layer, 7 — 1D stops, 8 — cylindrical lens, 9 — photodetector.

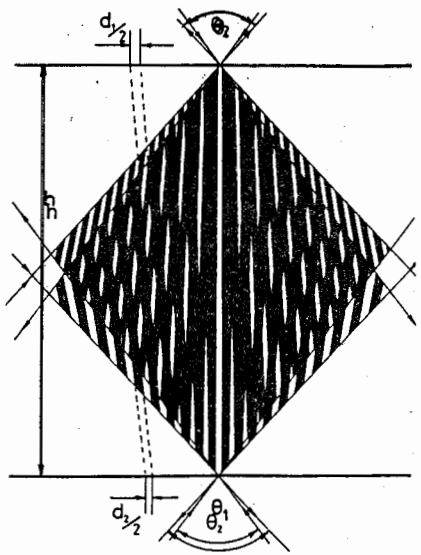


Fig. 4. An example of the overlapping pattern produced by the device with convergent cylindrical illuminating objective and with divergent cylindrical imaging objective.

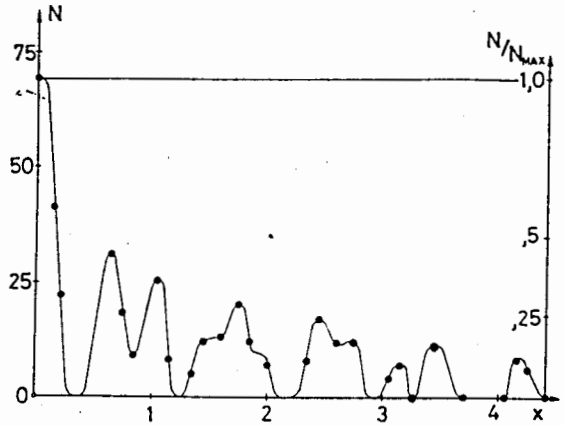


Fig. 5. The tabulated response of the confocal system with convergent and divergent objectives for vertical particle track with 75 silver grains in the nuclear emulsion layer of the depth 200 μm.

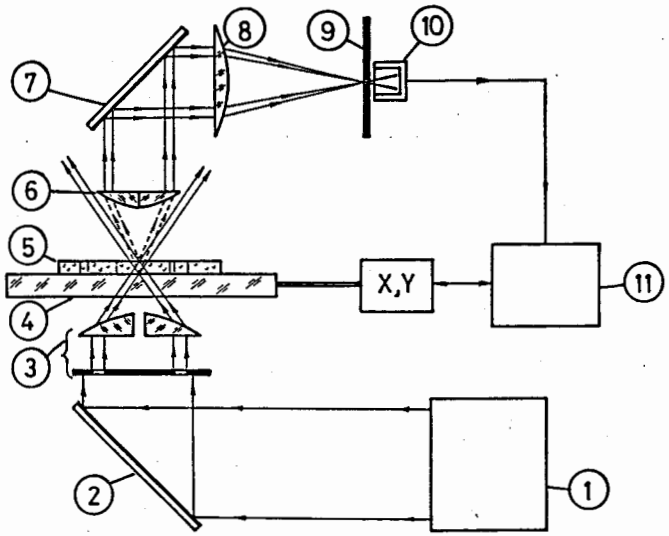


Fig. 6. Complete scheme of the new confocal microscope for selective observation of the vertical particle tracks with convergent and divergent geometries of the light rays in the illuminating and imaging objectives: 1 — laser, 2 — plane mirror, 3 — cylindrical interference illuminated system, 4, 5 — nuclear emulsion layer with vertical particle tracks, 6 — cylindrical interference imaging system, 7 — plane mirror, 8 — lens, 9 — pinhole, 10 — photodetector, 11 — computer.

two transfer functions of two objectives, of the illuminating objective and of the imaging objective.

In the meso-optical confocal microscope [5,7] the axial scanning along Z-axis is completely absent. Each objective of this microscope consists of two parts: a traditional lens-collimator and a multiaxicon. To hold the needed confocal topology of the light rays in such a meso-optical confocal microscope the following condition must be met: the light rays in the volume between two multiaxicons should be parallel in the meridional section of the object space.

Now let us consider the features of the new meso-optical confocal microscope with illuminating objective, which generates cylindrical convergent light rays, and with imaging objective, which generates the cylindrical divergent light rays. A typical example of the overlapping of two interference patterns is shown in Fig. 4. The tabulated response of this meso-optical confocal microscope is presented in Fig. 5 for vertical particle track with 75 silver grains in the nuclear photoemulsion layer of the depth 200 μm. We see that there are no side-lobes at all for comparative level of 37.5 silver grains. The transfer spatial resolution of this system is of the order of $0.95 \cdot 10^{-3}$ times the total transversal dimension of the illuminated region.

The construction of the proposed new confocal microscope with convergent light rays geometry in the illuminating objective and with divergent light rays geometry in the imaging objective is shown in Fig. 6. The laser 1 generates a collimated monochromatic light beam, which is reflected from the plane mirror 2 and is directed into the cylindrical interference illuminated system 3. The latter is provided with two eccentrical cylindrical lenses. The interference pattern is located in the nuclear photoemulsion layer 5 of the depth h. The diffracted light is picked up by the imaging objective 6 with focal length which is 1.62 times the focal length of the illuminating objective 3. The objective 8 and the pinhole 9 direct the diffracted light onto the point-like photosensitive element 10.

Let us consider the scanning operations in the proposed variant of the confocal meso-optical microscope. The $x-y$ stage of this microscope accomplishes the scanning operations prescribed by the following program in the computer 11. We consider an example of six vertical particle tracks inside the square to be scanned (Fig. 7). The first scanning operation is performed along x-axis by the illuminated region having narrow "fens" at the regime of the wide-row drill. After this first scanning operation we get one 1D-function $f(x)$, having six picks. The coordinates of these picks $x_1, \ldots, x_6$ of the function $f(x)$ define the positions of the $x - y$ stage of the microscope, at which the vertical particle tracks$1, \ldots, 6$ are successively in the centers of the illuminated region.

Before the second scanning operation, the imaging interference system 7 is to be rotated through the angle 90° in its plane. The response of our device in this configuration has a point-like structure, as two line responses of the systems 3 and 7 are now mutually perpendicular. The second scanning operations are performed six-fold along y-axis at x-coordinates $x_1, \ldots, x_6$ which are stored in the computer 11

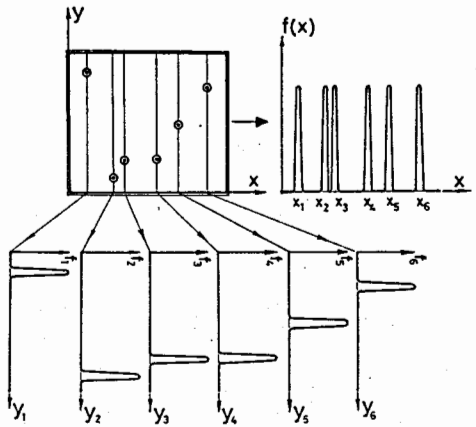


Fig. 7. Example of six vertical particle tracks shown as ⊙ inside the square to be scanned (see text).

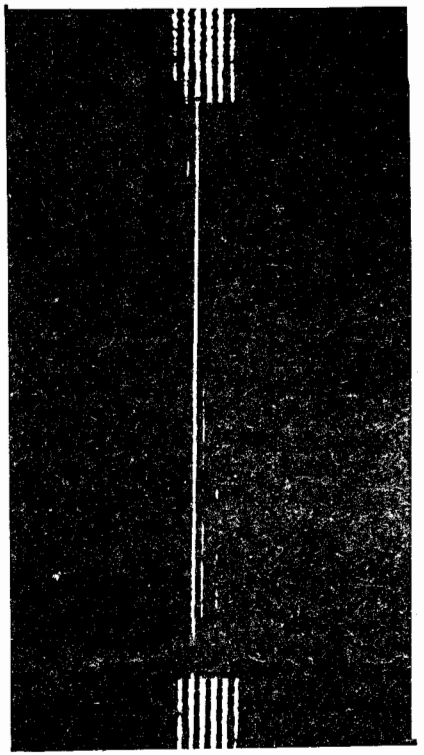


Fig. 8. Experimental setup used for observation of the interference picture produced by two cylindrical plane wavelets.

after the first scanning operation. Now we get six functions $f_1(y), \ldots, f_6(y)$ versus y-coordinate. The positions of six vertical particle tracks to be searched for are defined by six pairs of coordinates $(x_1, y_1), \ldots, (x_6, y_6)$, where $y_1, \ldots, y_6$ are the positions of the maxima of six functions $f_1(y), \ldots, f_6(y)$.

In general case of N vertical particle tracks inside the region to be scanned we must accomplish one 1D scanning with N picks in the function $f(x)$ and then N 1D scanning with one pick in each 1D plot. Thus the total number of 1D scanning is equal to $(N+1)$. For the quadrate region with sides of 5 mm length, we must make $5 \cdot 10^3 \cdot (N+1)$ digital measurements with spatial resolution of the order of 1 μm. Meanwhile in the traditional microscope the number of the digital measurements is equal to $(5 \cdot 10^3)^2 \cdot 30$. Here we suppose that the number of measurements along Z-axis in depth is equal to 30. Thus the factor of merits is equal to

$$\kappa = \frac{(5 \cdot 10^3)^2 \cdot 30}{5 \cdot 10^3 \cdot (N+1)} = \frac{15 \cdot 10^4}{(N+1)}.$$

For $N = 25$ we have $\kappa = 5.8 \cdot 10^3 : 1$.

4 EXPERIMENTS

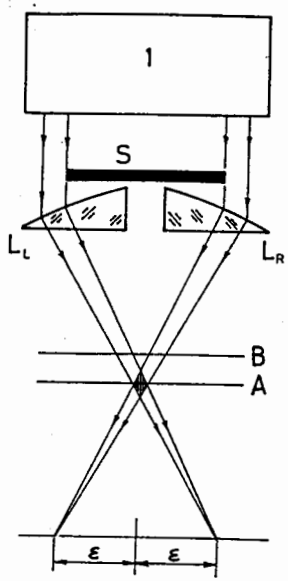
I. The interference pattern of two cylindrical waves has been observed in the conditions presented in Fig. 8. Two cylindrical half-lenses L_L and L_R are illuminated by the plane wave from laser 1. The stop S restricts to external parts which are focused independently at eccentricities $\pm\varepsilon$. The photoplate 2 is located in various positions: in the plane A during the first exposure and in the plane B during the second exposure. In the position A two cylindrical waves are overlapped, but in the position B they are separated by the distance which is more than the transversal width of the cylindrical waves. Two microphotographs taken in the planes A and B are shown in Fig. 9, "A" and "B". The number of the contrast interference fringes is equal to 7.

II. Two interference pictures with two different fringe periods, in the ratio 1.62 : 1, have been prepared. The mechanical mounting of these two photos is shown in Fig. 10. We see that the number of contrast maxima in this combined mounting of two transparencies is equal to one instead of seven, observed in each interference pattern. To get such an amelioration in the total point spread function of our confocal system, the focal lengths f_1 and f_2 of two half-lenses L_1 and L_2 must be in the ratio $f_1 : f_2 = 1.62 : 1$.

5 CONCLUSIONS

1. There are proposed principally new constructions of the confocal meso-optical microscopes for selective observation of the vertical particle tracks in the nuclear photoemulsion layers.

Fig. 9. The microphotographs taken in the planes A and B of the experimental setup shown in Fig. 9.



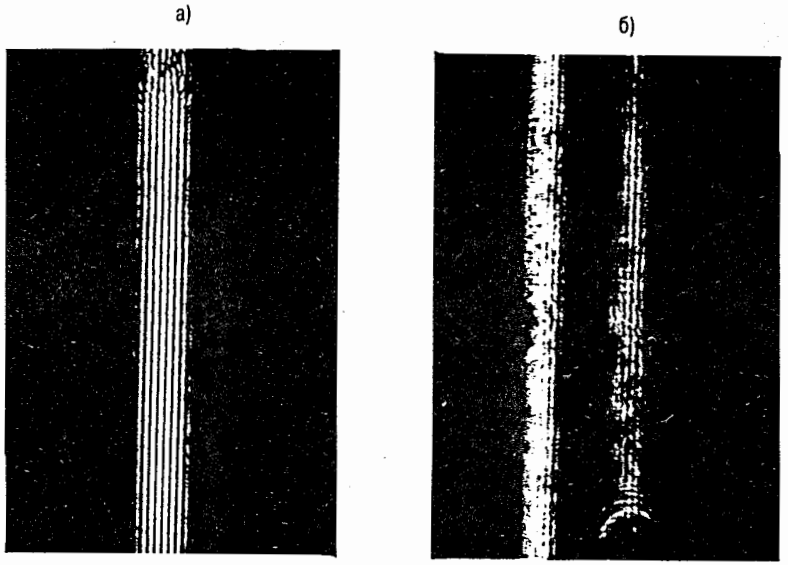


Fig. 10. The transparencies mounting of two interference pattern taken at two different fringe periods in the ratio 1.62 : 1.

2. The most promised construction involves convergent-divergent geometries of the light rays in the illuminating objective and in the imaging objective.

3. The experiments which illustrate directly the main features of these new microscopes have been performed.

4. There are proposed principally new two stages scanning algorithms which suit well to these confocal meso-optical microscopes and which involve only $(N+1)$ 1D scanning operations with N – number of the vertical particle tracks in the square to be searched. The factor of merits of two stages scanning algorithms for quadrate region with sides 5 mm and with spatial resolution of the order of 1 μm is equal to $\kappa = 5.8 \cdot 10^3 : 1$ for $N = 25$.

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