Completely Automated Measurement Facility (PAVICOM) for Track-Detector Data Processing

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TECHNICAL DESCRIPTION

The PAVICOM consists of two automated microscopes (Fig.1). The first of them, (PAVICOM-1) includes the precision-mechanics stage made (in 1999) by the German MICOS company on the basis of a Pentium II personal computer on base. The software includes, in part, CERN-CHORUS program library and the VS-CTT digital system for computer-based image processing (with the relevant hardware and software).

The precision-mechanics stage parameters are the following:

–- the displacement lengths along the X-, Y-, and Z-axes are 800, 400 and 200 mm, respectively;

-- the displacements along all the axes are governed by a controller in accordance with computer commands with an accuracy of 0.5 micron;

-- the stage sizes are 2.5m $\times$ 1.2m $\times$ 2.4m;

– the total mass of the stage is about 1000 kg.

The MICOS stage is placed into a special clean room with a stable temperature and humidity.

The VS-CTT digital system parameters are:

– 1024 levels of the amplitude-digital conversion for optical images ;

– the 1360 $\times$ 1024 pixel frame size;

– the 4.65 $\times$ 4.65-micron size of an individual pixel .

The PAVICOM-2 includes a precision-mechanics stage made (in 1998) by Carl Zeiss company; a LOMO microscope with magnification to 1000×; a personal computer on the basis of Pentium II; a CCD-camera with the relevant hardware and software, which transmits a digital image at the computer.

The Carl Zeiss mechanics-stage parameters are the following:

-- displacement lengths along the X- and Y-axes are 100 and 100 mm, respectively;

– displacements along all the axes are governed by a controller according to computer commands with an accuracy of 0.5 micron.

The CCD-camera parameters are:

-- 256 levels of the amplitude-digital conversion for optical imaging ;

-- the 597 $\times$ 537-pixel frame size;

-- the 12.7 $\times$ 8.3-micron size of an individual pixel.

PRESENT STATUS OF THE PAVICOM.

Universality and a high operation rate of the PAVICOM provide opportunities for processing data obtained as a result of several experiments. Among them there are the following important experiments:

(a) investigating properties of the multiparticle-generation process, in particular, search for manifestation of quark-gluon plasma in central collisions of ultrarelativistic heavy nuclei (EMU-15 project performed by the LPI at CERN);

(b) studying the nuclear composition and the energy spectrum of primary high-energy cosmic rays by direct methods in the framework of the Russian-Japanese RUNJOB collaboration (MSU, LPI, and 6 JAPANESE UNIVERSITIES);

(c) studying neutron multiplication in extended blocks of heavy elements exposed to the proton beam of the Dubna synchrophasotron (Energy + Transmutation experiment in JINR;

(d) automated data scanning and processing in nuclear emulsions irradiated at the ITEP and JINR beta-spectrometers;

(e) determining the nuclear composition of primary cosmic rays of solar and galactic origin by means of solid-state detectors exposed aboard the MIR and MKS Space Stations (the PLATAN experiment of PTI, Saint Petersburg).

FUTURE PLANS.

The completely automated facility PAVICOM turns out to be sufficiently universal; it may be used to fulfill measurements both for the current and for the planned experiments.

I. “Repeated processing of unique events”.

II. The “BECQUEREL Project”

III. The “Solar Sail Project”.

E.L.Feinberg near PAVICOM-1

N.G.Poloukhina near PAVICOM-2

Fig.1. PAVICOM.

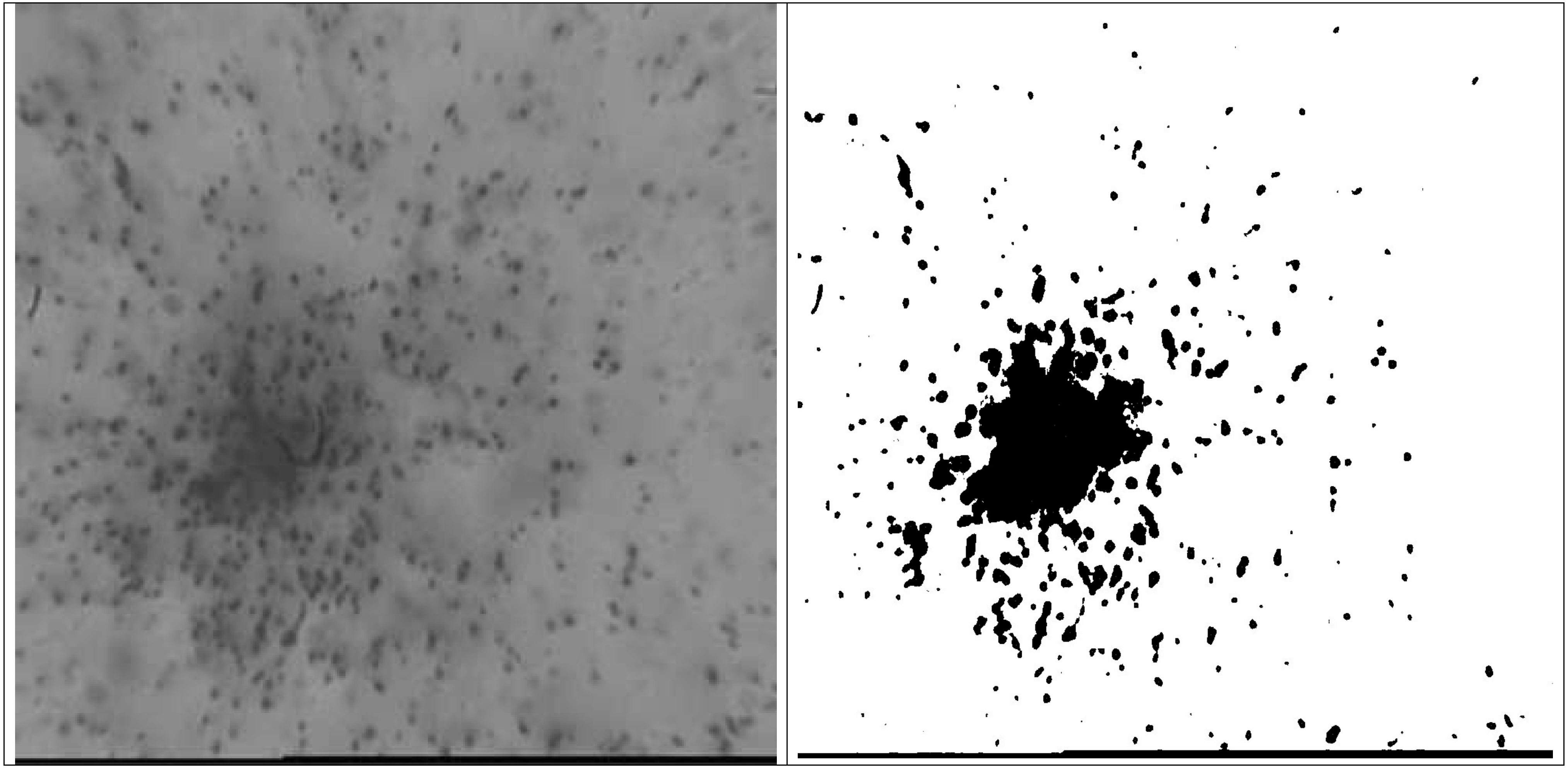


Fig.2a.
Emulsion image of central field of view Pb-Pb interaction with 158 Gev/nucleon; "CLUSTERING" program treatment result for this field of view (size field of view is about 75*75 microns)

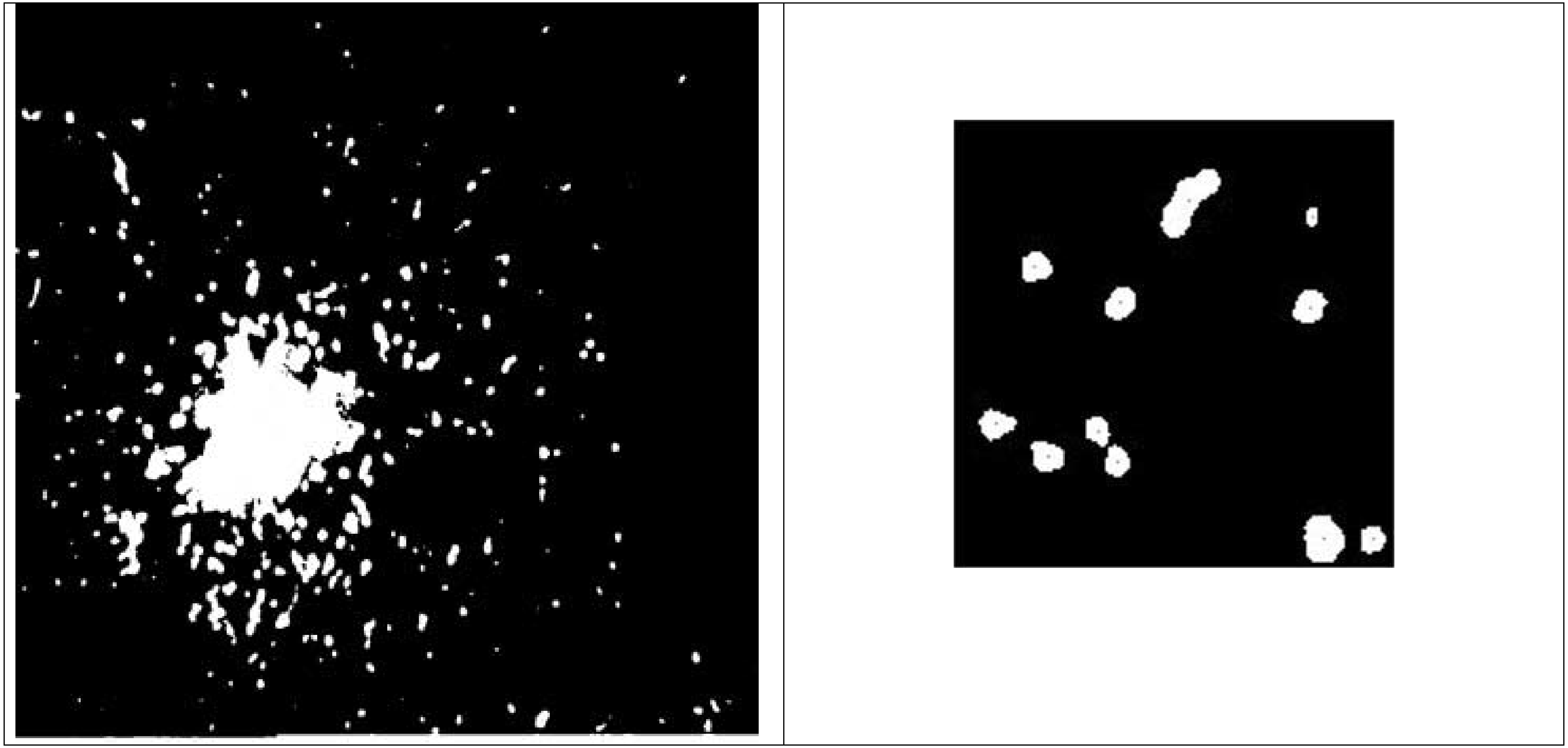


Fig.2b.
“TRACKING” program treatment result for the same field of view; part of this frame showed “mass center” of some clusters.

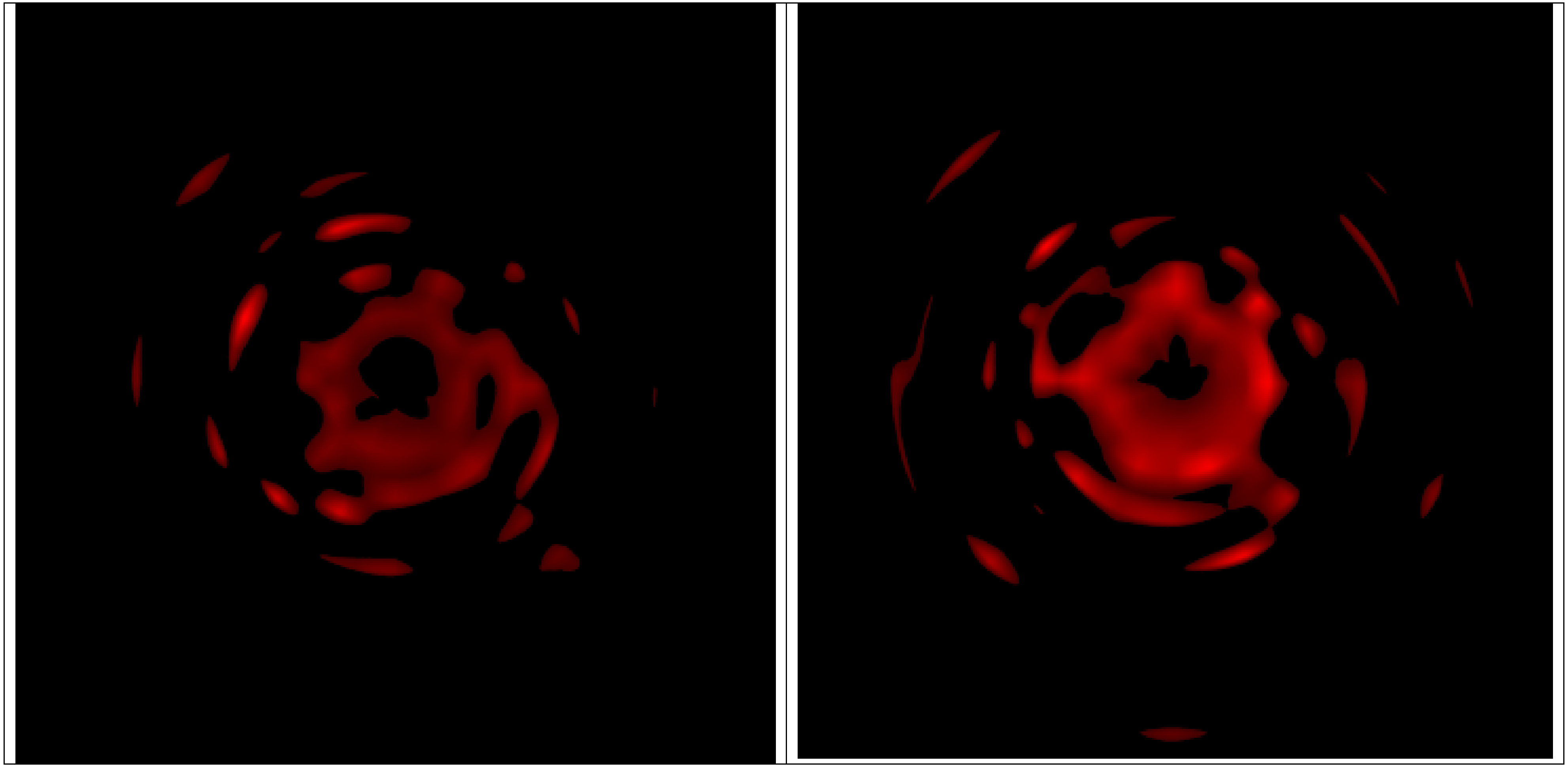
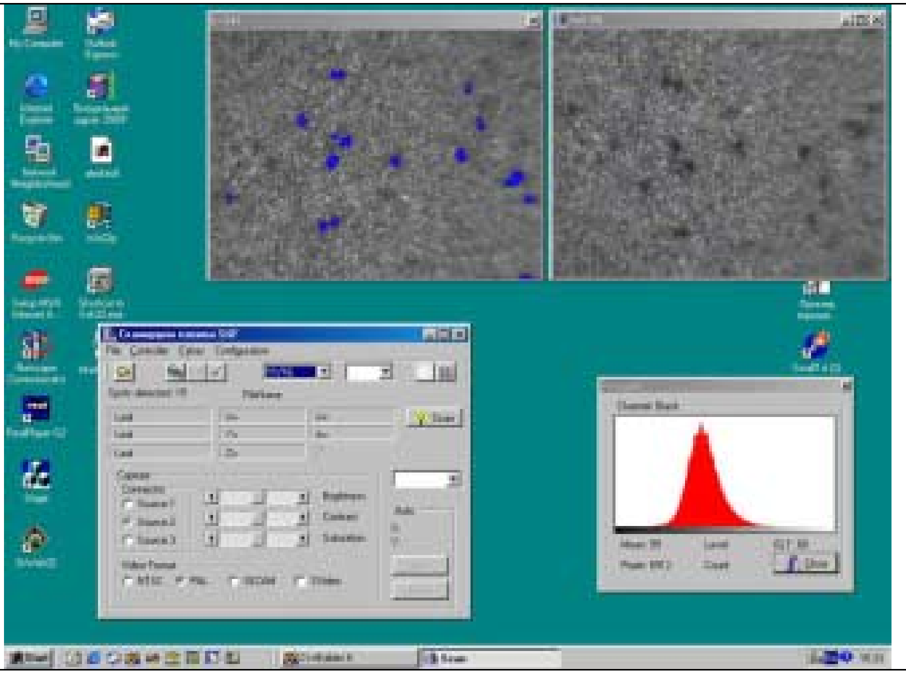
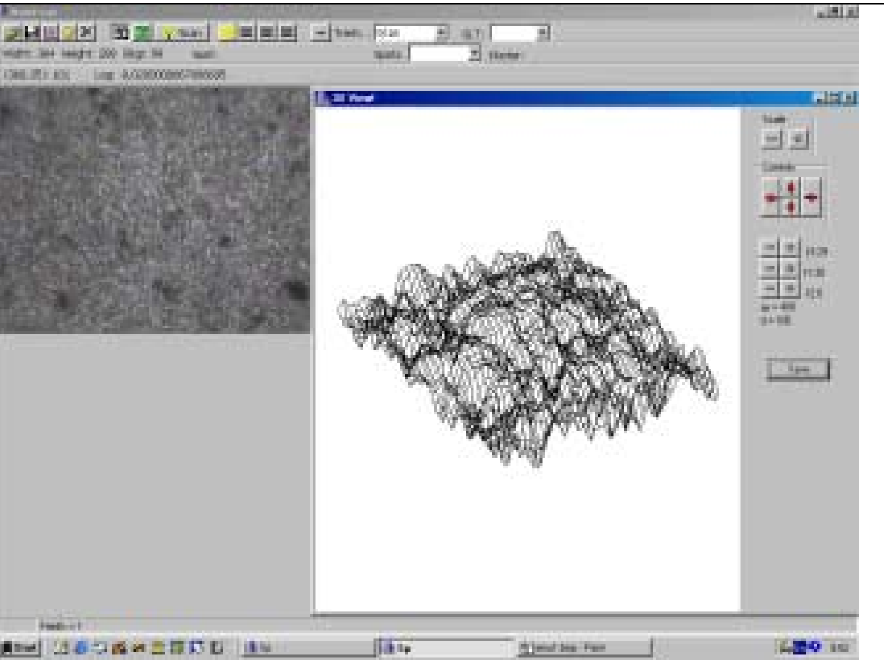


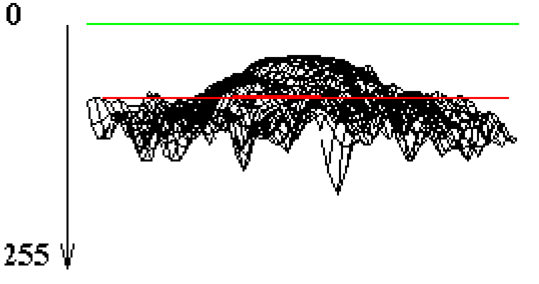
Fig.2c.

Examples of wavelet-coefficient distributions for two experimental events Pb-Pb central interactions (at polar coordinates – angle and pseudorapidity, intensity of color correspond to larger coefficient values).





The SXF image obtained by CCD-camera.



Three-dimensional contour map corresponding to one spot in SXF.

Fig.3. Example of RUNJOB program screen and treatment.

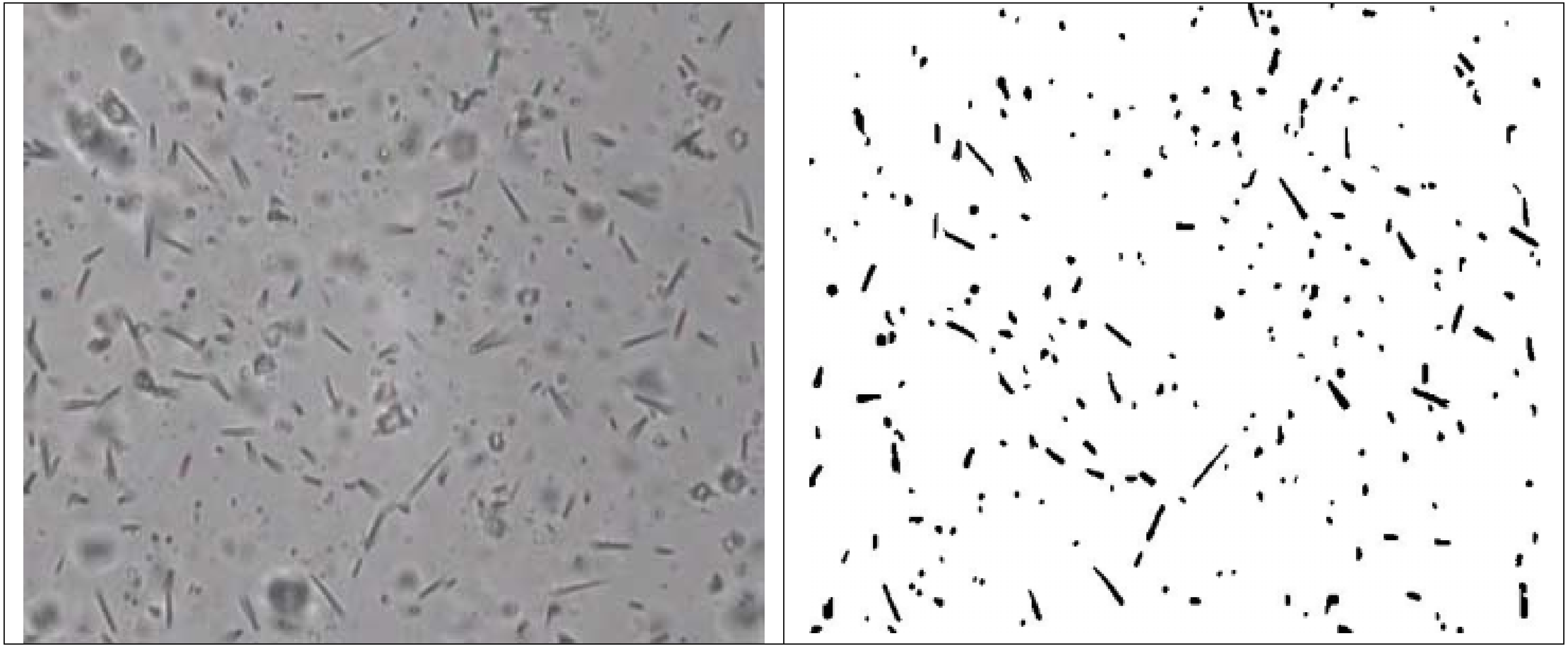


Fig.4
Examples of neutron multiplication registered in solid thin layer tracker; left – tracker image, right – image recognition by PAVICOM.

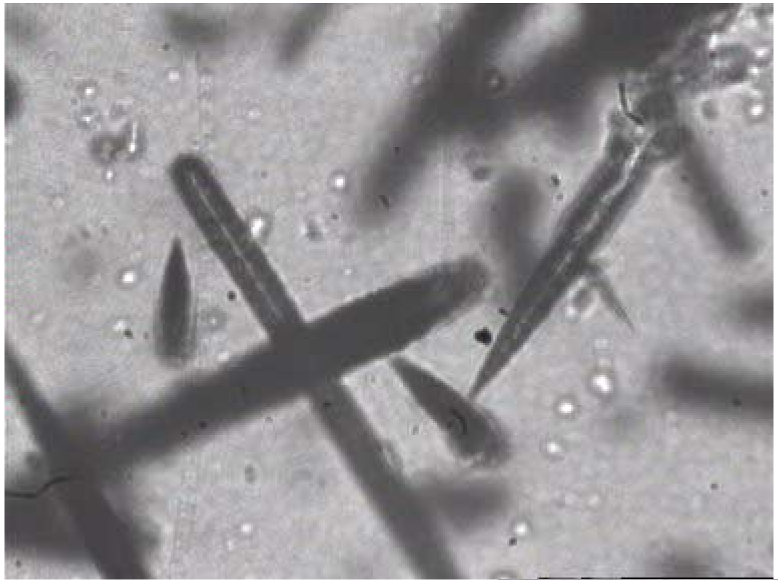
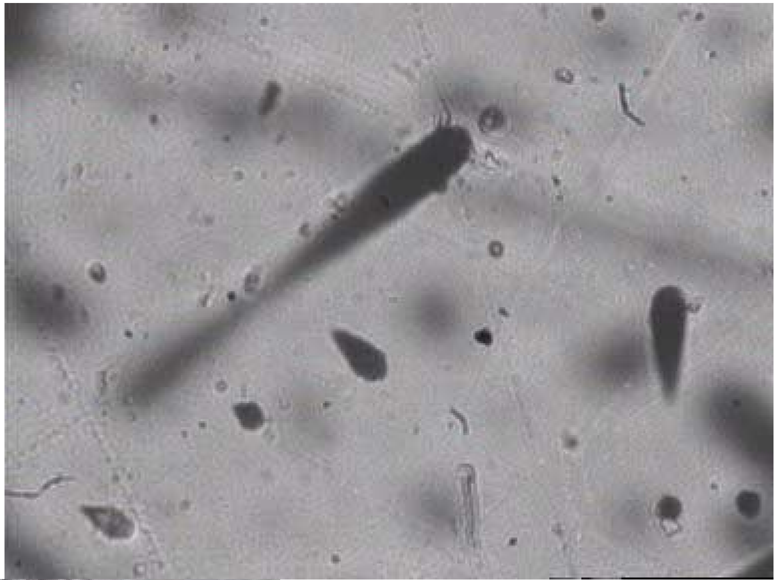




Fig.6. Image example of cosmic rays tracks at CR-39 at PAVICOM.

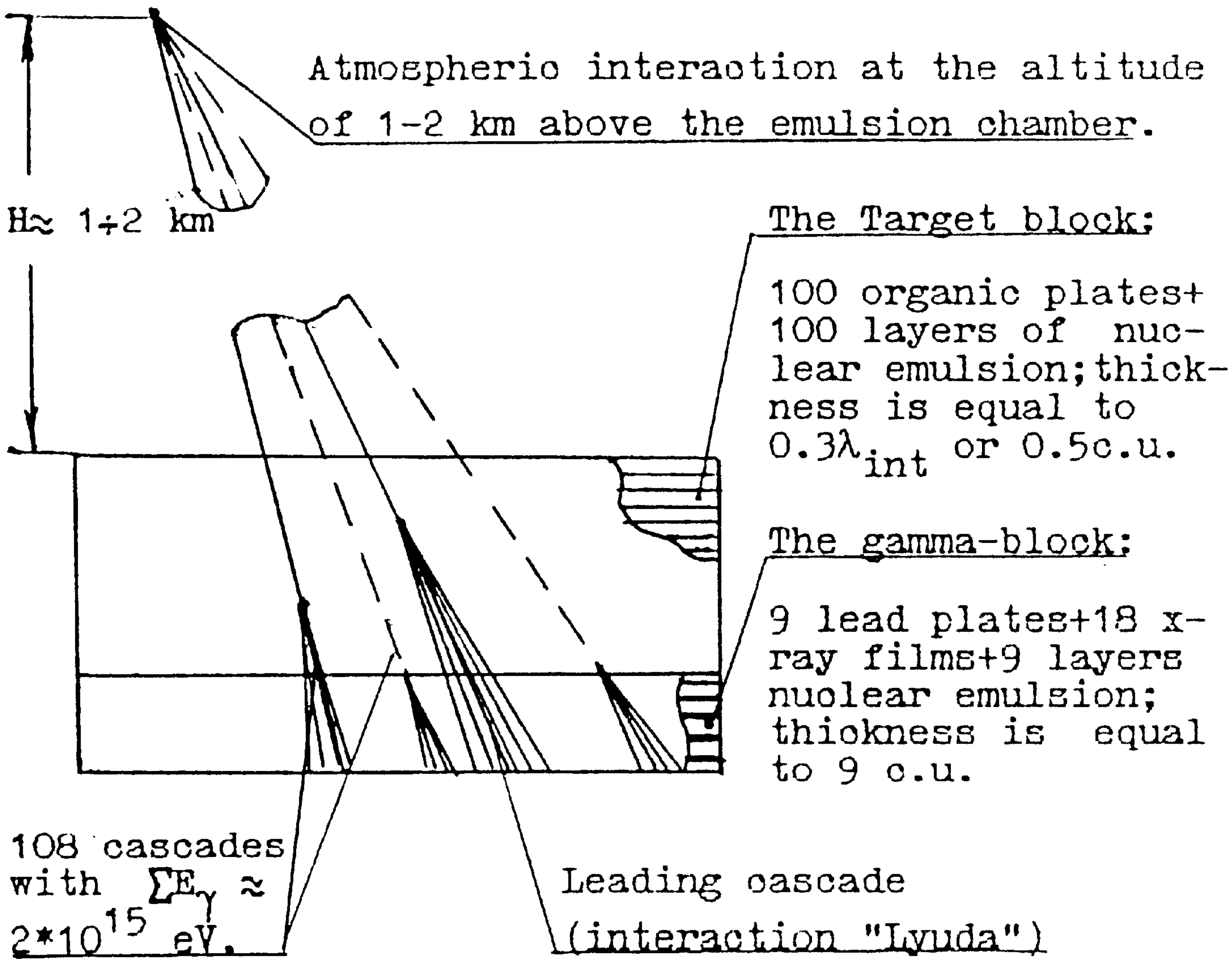
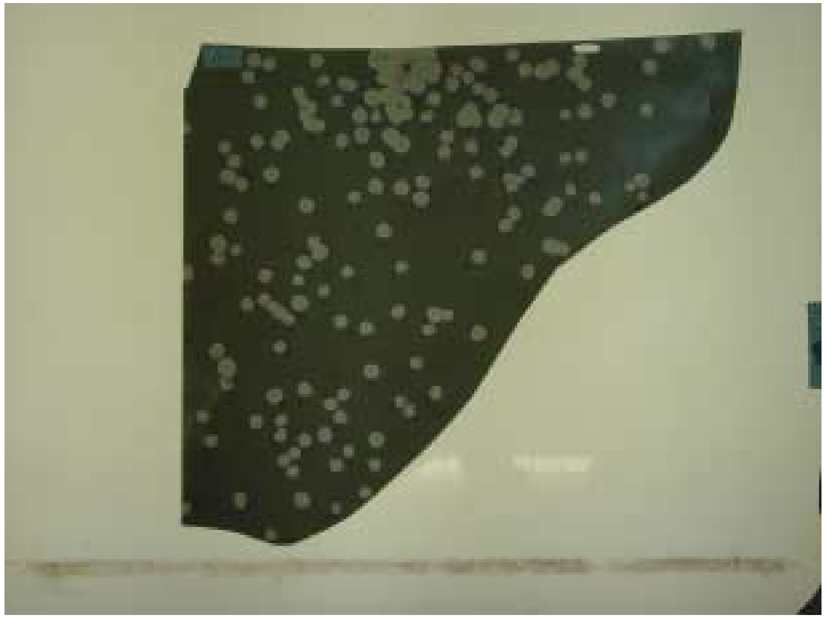


Fig.7. Chamber scheme with registered family "STRANA"



Part of 7-th layer of chamber with registered family "STRANA"

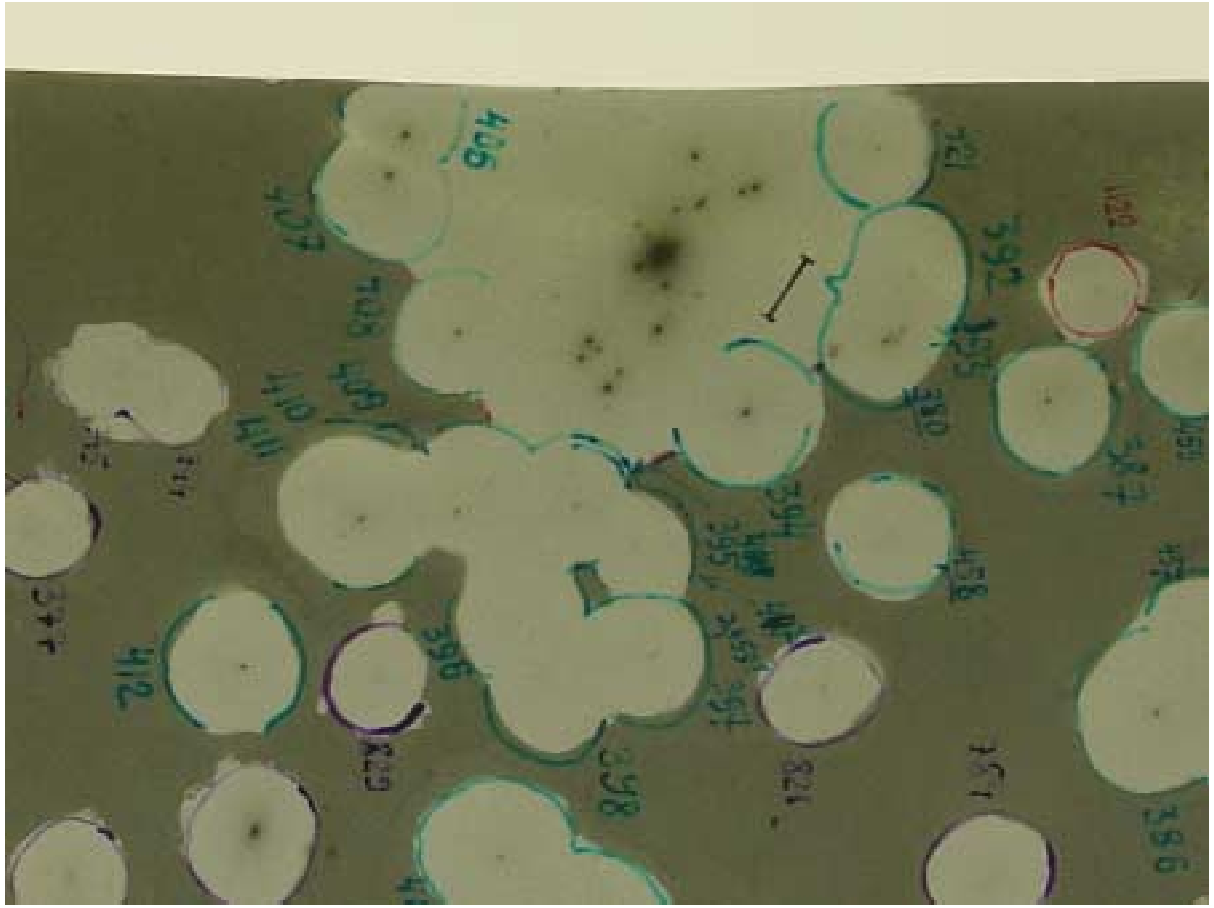
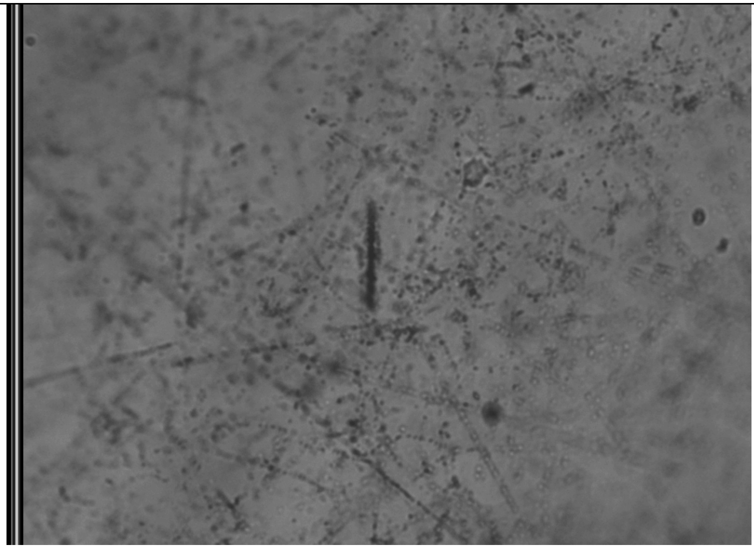
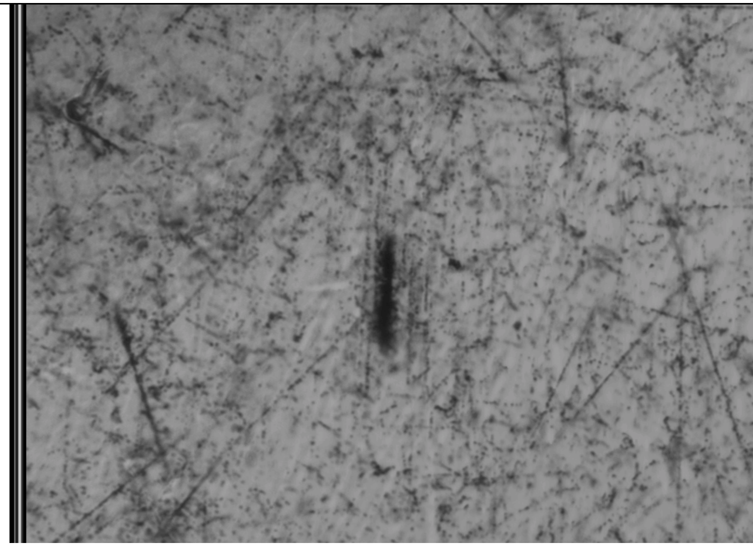


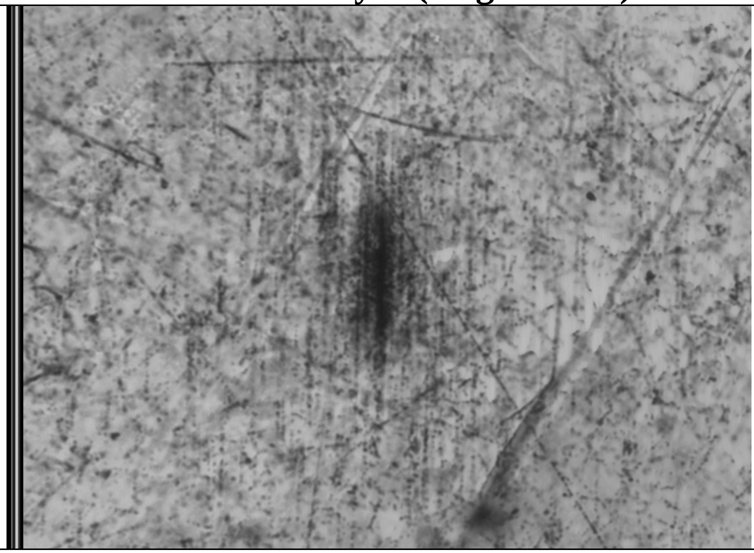
Fig.8

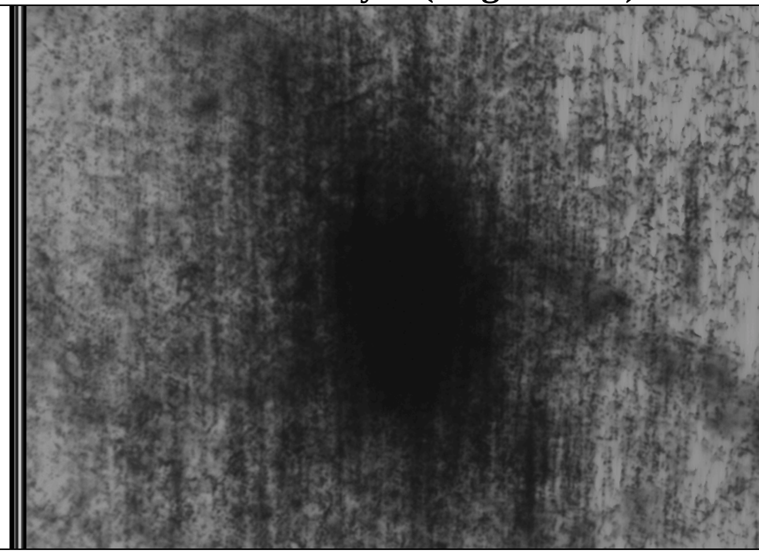


13 emulsion layer (target block)



30 emulsion layer (target block)

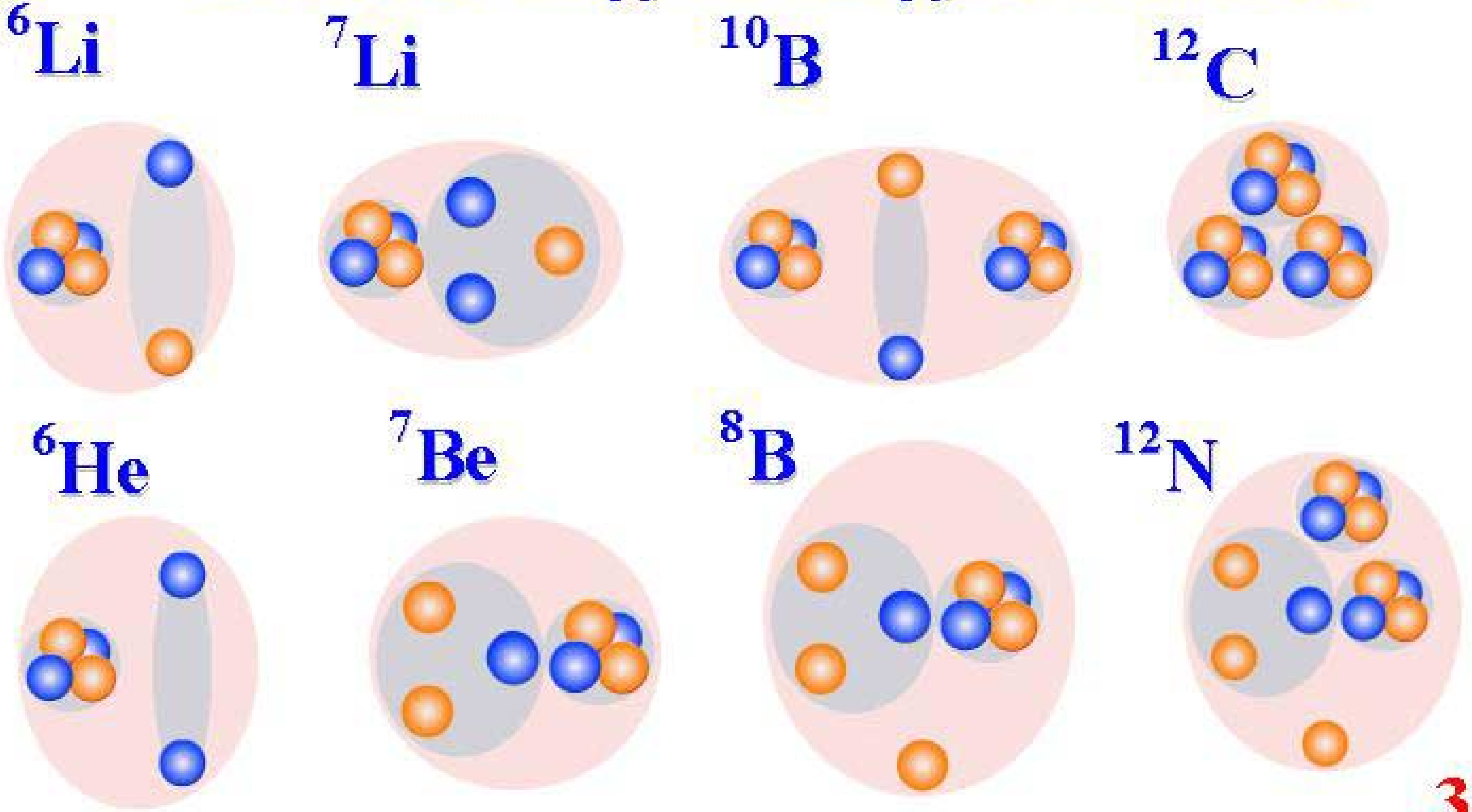


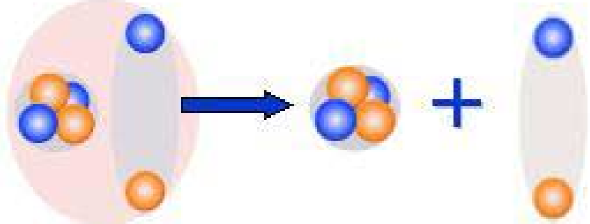


99 emulsion layer (target block)	102 emulsion layer

Fig.9. Images of leading particle cascade in nuclear emulsion of stratospheric family STRANA.

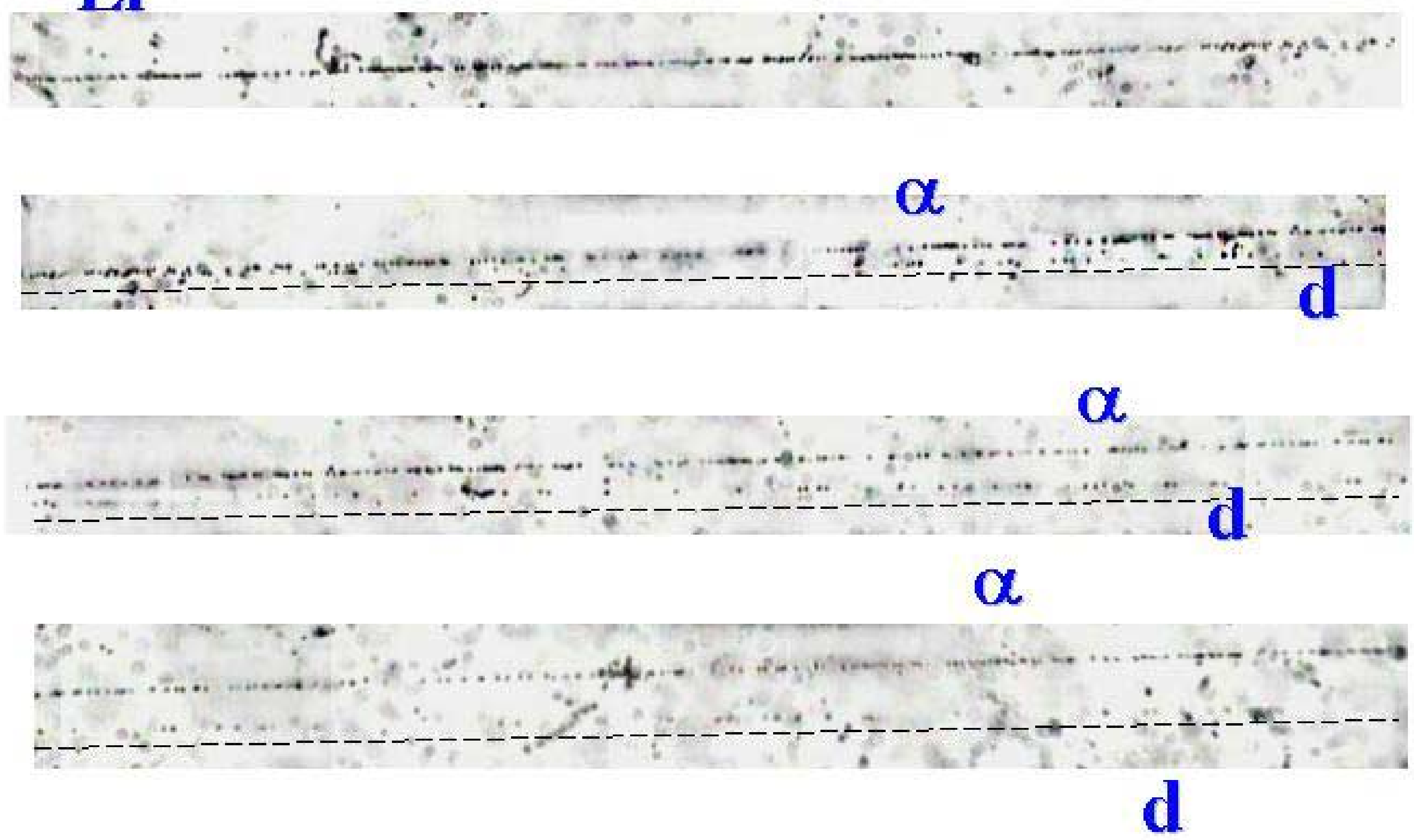
Clustering in Light Nuclei





^6Li

4.5A GeV/c ^6Li Coherent Dissociation (PAVICOM image)



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INTRODUCTION.

A very efficient Completely Automated Measuring Complex (PAVICOM) for track-detector data processing in the field of nuclear and high-energy particle physics has been constructed in the Lebedev Physical Institute (LPI) [1, 2]. The PAVICOM provides the essential improving the efficiency of experimental studies performed by Russian Institutes in the field of nuclear physics and cosmic-ray physics using emulsion trackers or/and solid-state film trackers.

In contrast to semi-automated microscopes widely used until now, the PAVICOM is capable of performing completely automated measurements of charged-particle tracks in nuclear emulsions and tracks of high-energy nuclei in X-ray films and in solid-state detectors without employing hard visual work. In this case, track images are recorded by CCD-cameras and then are digitized and converted into files. Thus, experimental-data processing is accelerated by approximately thousand times.

Completely automated devices similar to PAVICOM came into operation in scientific centers of Japan, Italy, CERN, and some other countries. In Russia, the PAVICOM is the only facility of such a type. Its possibilities are so wide that satisfy not only needs of investigations being performed in LPI but are also used by other Russian laboratories and Institutes. Thus, PAVICOM actually plays the role of multiporpuse user center.

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(a) The EMU-15 experiment has been performed at CERN by an LPI group for studying characteristics of high-density and high-temperature nuclear matter, in particular, for searching for manifestation of the quark-gluon plasma.EMU-15 emulsion chambers were exposed to the CERN lead-ion beam with an energy of 32 TeV per nucleus. The main problem inherent in these investigations is a large amount of track measurements in nuclear emulsions. Evaluating the scale of this work shows that it is necessary to measure about ten millions coordinates of secondary particles in the nuclear emulsion for processing 100 central Pb–Pb interactions recorded in the emulsion chambers. Such a work cannot be done without the PAVICOM. In 2001, the test processing of central Pb-Pb collisions was made. This revealed certain difficulties of measurements, e.g., a necessity of tuning different fields of view, of tracing each track in adjacent nuclear-emulsion layers, and other problems (Fig.2).

(b) Studying nuclear composition and primary cosmic-ray spectrum was performed within the RUNJOB experiment (using stratospheric X-ray emulsion chambers. The main goal was to develop and to apply to experimental data the new method of selecting heavy nuclei, which is based on scanning of SXF screen-type X-ray films that allows us to decrease the energy threshold in recording heavy nuclei and gives a possibility to obtain within a unified experiment the energy dependence and intensity ratio for nuclei with $Z > 17$ and $Z = 17$--24 within the energy range 0.1 -- 100 TeV/particle.

A SXF consists of two intensifying screens and one X-ray film inserted between them. When a heavy primary nucleus passes through a SXF, scintillation light is emittted from both screens so that X-ray film records a double dark spot, which can be seen by a naked eye. Primary and target blocks of each chamber contain 10 SXF layers whose size is $400 \times 500 mm^2$. The spot intensity at the SXF equals 200 cm^{-2}(see fig.3).

The software for SXF automated scanning was create, which included the automated steering of the MICOS microscope mobile stage; the pattern recognition of spots in the SXF, which were induced by heavy nuclei; and the unification of all detector layers in the emulsion-chamber coordinate system.

The scanning total time per one film is 11--12 hours. For each spot coordinates, the spot size, the value of the darkness at the spot center, and the average darkness for the entire spot weare measured.

All SXF films for the Russian part of experimental data were processed with the help of the PAVICOM. The measurements were performed many times for different scanning parameters determined by different approaches to the nuclear-track pattern recognition. Tracks of heavy nuclei were reconstructed in the natural scale of the chamber volume. The charge and angular distributions for nuclei recorded and the efficiency of particle detection were determined. The accuracy of track-coordinate measurement was better than 150 micron at chamber area equal to 400×500 mm^2. Thus, the efficiency of the search for nuclei was about 100%. This search was made in an automated regime. The indication for a track being searched for was obtained in a time shorter than 15 s. After completion of this procedure, the stage automatically moved to a necessary point. We plan to study nuclei interacted within the chamber target. The amount of such nuclei is about 3% from the total nucleus flux. Now, the development of a software for searching for nuclear tracks and nuclear-energy determination are in progress.

(c) Studies of the neutron multiplication in extended heavy-elements blocks were performed by exposing them to the proton beam of the Dubna synchrophasotron. The electro-nuclear method of nuclear energy production using a proton beam of the synchrophasotron is well known. The concepts of constructing hybrid electronuclear systems that combine a proton accelerator, a heavy-element target to generate intense neutron fluxes, and fissile target environment is a very important among several approaches to solve the problem of future development of nuclear-energy production. A solid-state tracker was suggested as a neutron detector for this experiment [3]. The corresponding software was developed for processing patterns in such solid-state detectors at the PAVICOM. This software allows us to recognize (in automated regime) particle tracks and determine their concentration. The complete treatment of experimental data obtained during two measurement runs was carried out with the PAVICOM. Thereby, the efficiency and reliability of such a method was confirmed. The development of the software for treatment of large-intensity neutron fluxes recorded in solid-state detectors is continued with allowance for effects of possible overlapping close tracks, (see fig.4)

(d) A new optical system for the PAVICOM-1 was used by scientists of the Institute of Theoretical and Experimental Physics to perform test measurements in a nuclear emulsion irradiated by electrons in the JINR beta-spectrometer. The measurement results are promising from the standpoint of a possibility to recognize lines, corresponding to nuclear excited states. (see Fig.5).

e)The solid-state detectors were used by S.-Petersburg Physical-Technical Institute for studying fluxes of primary cosmic rays of solar and galactic origin. At the present time, a block of such detectors is installed aboard the MKS for the exposure in space. After exposure and development, these detectors will be processed with the use of PAVICOM. The series of nuclear tracks in CR-39 have been measured with PAVICOM and CD-disks were passed in PTI for elaboration of software (fig.6).

FUTURE PLANS.

The completely automated facility PAVICOM turns out to be sufficiently universal; it may be used to fulfill measurements both for the current and for the planned experiments.

I. “Repeated processing of unique events”.

The repeated processing of x-rays-emulsion chambers, irradiated by cosmic ray in the course of the first LPI balloon experiments is planned. In particular, the unique gamma-hadron family with the total energy in excess of 10^{16} eV named “STRANA” recorded at the altitude of about 30 km, is very unusual and interesting [4] (fig.7).

Multilayer x-ray-emulsion chamber consists of a target, space blocks and a calorimeter. Target block consists of 100 emulsion layers each thick 50 microns, inter-layered by plastic 1.5 mm thick. The spacer has 10 emulsion layers inter-layered by plastic 5 mm thick. The total thickness of the target and the space blocks is equivalent to about 0.5 cascade units or 0.3 proton mean free path for nuclear interaction. In the calorimeter nuclear and x-ray films were inter-layered by 9 lead layers each thick 5 mm. The total calorimeter thickness was 9 cascade units or 0.26 mean free path for nuclear interaction.

Fig.8 presents photo of gamma-hadron family in the calorimeter. The family consists of 107 cascades (76 gamma-quanta and 30 hadrons, one leading particle). The energy of the air family with all corrections taken into account is about $0.9*10^{16}$ eV excluding the energy of the leading particle.

The high energy leading particle interacts in 13 layers of the target block resulting in the narrow jet of secondary particles (fig.9). This jet quickly developed at carbon target and produced the large dark spot at the family center at x-ray films of the calorimeter. The energy of the leading particle evaluated using pseudorapidity distribution and model calculation was about 10^{16} eV.

So, the total energy of primary particle is about $2*10^{16}$ eV.

Recently repeated processing of this unique event (family “STRANA”) of the world experimental data started. It was impossible to complete processing of such event before because of technical problems.

II. The “BECQUEREL Project”

This program persues two objects: first, further investigation of possible cluster (molecular-like) configurations in some light nuclei, and second, search for some additional (unconventional) ways in nucleosynthesis.

The Dubna nuclotron facilities are quite favorable for studying the light nucleus fragmentation after their scattering off the emulsion nuclei. Observation of namely this process is to be made be by singling out collisions with low momentum transfers and, especially, the coherent dissociation of the light nuclei (when the emulsion target nuclei remain unexcited), since intermediate compound nuclei produce such final states with very low probability. The well known example is the coherent dissociation of Li^6: the relative rates of the final states He^4-d, He^3-T, He^4-pn and ddd are described as 23:4:4:0, what certainly evidences that the main term in decomposition of nucleus Li^6 wave function is the production of two cluster function, He^4*d, the binding energy between them being rather small, i.e., that nucleus Li^6 shows up the corresponding molecular-like structure.

Search for new ways in nucleosynthesis is associated with production and studying the sufficiently long-living radioactive isotopes of light nuclei, namely, the extremely proton- or neutron-enriched ones which show up a pronounced proton or neutron halo. At proper energies, these nuclei are expected to have the abnormally large effective radii and cross sections, especially in reactions of fusion with the complementary ones. This is just what is to be analyzed in the planned experiments. If these expectations turn out to be true, then the overall pattern of nucleosynthesis at the early stage of Universe evolution is to be revised by allowing for some additional cycles.

III. The “Solar Sail Project”.

At the present time, in Russia, USA and Europe the works on designing a “Solar Sail Ship” is performed. “SSS” is a space satellite which has a thin film sail with area of about few thousands square meters and moved by solar light pressure. This works stimulated the development of a technology for manufacture and unwrapping in space of a thin film structure of large area (TFS). TFS possibilities could be very interesting for various scientific and technological applications. LPI together with Babakin Center proposed a wide astrophysical program, which include experiments on measurements of the magnitude and variations of cosmic nucleus fluxes [5,6].

The interest to nucleus component of cosmic radiation of solar origin is very high and is determined mainly by a possibility to investigate processes in the solar crown and in space. For example, determination of geomagnetic threshold for different nuclei of this radiation allows one to determine charge states of nuclei and thus to receive a very important information on temperature in that Solar crown regions, which particles were include to acceleration process. Besides that, it is interesting to investigate flux magnitude and the energy spectrum of nuclei and connection of these characteristics with Solar flares, shock waves and so on.

Possibility of TFS using as a thin solid-state detectors is very attractive. By using 2-3 layers of detector implies identification of low-energy nuclei, which have a short range and stop in these layers (of course, high energy penetrating nuclei will be registered too). Fe nuclei with energy 5-14 MeV/nucleon will stop in such layers of total thickness about 300 microns. Abundance of lower energy nuclei of galactic cosmic ray (GCR) is very low. Thus, measurements large area detectors is important for these nucleus flux.

Today the studies of GCR in the energy region of about tens of Mev per nucleon are only starting. The statistical errors are very large, and it is impossible to determine the energy spectrum shape for low energy nuclei, as well as to interpretate nusleus origin. There are no virtually any experimental data on superheavy nuclei with Z>30, which relative abundance is few thousand times less that for Fe nuclei for this energy region. Large area detectors (about few hundred square meteres) allows problem of such nuclei registration to solve. At the same time, Fe ion flux of solar cosmic ray in this energy region is near maximum value for this spectrum, and, so, it is possible to record them even in small solar flares. For power solar flares it is possible to investigate nucleus flux variation in time, if TFS will be used with moving layers. Relative layers motion converts TFS from intergal detector to differential in time one. Such layer motion will allows for separating GCR nuclei from SCR nuclei, and for separating particles from different solar flares.

Multifilm construction of SSS is shown in fig.11. The construction consists of two external and one internal layers. Each external layer is glued from 2 films of 20 micron thick. The internal layer is glued from 9 similar films. Thus for nuclei normally incident on the installation, their range in the film will be measure with the accuracy of about half of the total film thickness, i.e. about 1 mg/cm^2.

For measurements of two point in time at which nuclei have gone through the multifilm setup, it is suggested to move the external layers relative the lateral one during space exposure. Due to such possibility as energy value will be record as nuclei registration time will be determinate.

The minimum energy is determinated by the requirement that the particle range is about 5 mg/cm^2, i.e. it is possible to measure 2 films of moving layer and 1 film of internal layer. The maximum energy is determinate by the requirement that the particle range is about 26 mg/cm^2 and particle has been recorded by all 13 films.

Our calculations show that the maximum nucleus energy is about 10 Mev/nucleon. The geomagnetic thresholds for such nuclei are at 60 degree latitude. Thus, it is necessary to mount multifilm setup on a satellite with the orbit inclination of about 80 degree, and exposure should be made in the start-stop regime. In such regime, special marker halls will be done in films at the moment of crossing by satellite 60-th latitude. After that the external layers of the setup will be moved along the internal layer with a constant speed of about 2 mm/s. After leaving polar latitudes the motion will be stopped, and new marker halls will be done.

After returning to Earth, films will be developed and processed with the PAVICOM, which allows for treatment of solid detectors of large areas. Exposure of multifilm setup with area of about 100 m^2 installed on a small space satellite will allow to receive experimental data on solar and galactic cosmic nuclei. Experimental statistic of such events will be enough for geomagnetic threshold determination for different nuclei, for finding charge states of nuclei, their energy spectra, intensity etc. These results will be valuable both for solving some astrophysics problems, and for some practical applications, for example, for cosmic meteorology.

CONCLUSION.

Thus, possibility of a completely automated experimental data processing with a high rate allows for using PAVICOM in studies with utilization of the track detector method [7]. On the basis of the PAVICOM-processed data one PhD and one professor dissertations was successfully defend, and new PhD dissertation represent to defend now. The great prospects offered by the PAVICOM make possible to schedule new emulsion experiments and fulfilling repeated processing of previously obtained interesting emulsion data.

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