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Completely automated measurement facility (PAVICOM) for track-detector data processing

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Abstract

A review of technical capabilities and investigations performed using the completely automated measuring facility (PAVICOM) is presented. This very efficient facility for track-detector data processing in the field of nuclear and high-energy particle physics has been constructed in the Lebedev physical institute. PAVICOM is widely used in Russia for treatment of experimental data from track detectors (emulsion and solid-state trackers) in high- and low-energy physics, cosmic ray physics, etc. PAVICOM provides an essential improvement of the efficiency of experimental studies. In contrast to semi-automated microscopes widely used until now, PAVICOM is capable of performing completely automated measurements of charged particle tracks in nuclear emulsions and track 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 a thousand times. Completely automated facilities similar to PAVICOM came into operation in scientific centers of Japan, Italy, some other countries, and in CERN. In Russia, PAVICOM is the only facility of such a type. Its capabilities are so wide that it serves not only the needs of investigations being performed at the LPI but is also used by other Russian laboratories and institutes. Thus, PAVICOM actually plays the role of a multipurpose user center.

1. Introduction

PAVICOM (completely automated measuring facility) is a unique highly effective measuring facility for processing experimental data from nuclear emulsions and solid-state track detectors. The installation was devised in 2000 by Lebedev physical institute scientific group headed by Academician E.L. Feinberg [1–4]. PAVICOM had been created for the purpose of high-technology treatment of experimental data in the fields of nuclear physics, cosmic ray physics and high-energy physics. The following operations can be executed in completely automatic regime:

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(1) search and digitization of charged-particle track coordinates in the detector material; (2) computerized track identification and tracing; (3) data systemization and primary treatment. First completely automated processing systems were put into operation in Japan during the 1990s. Currently there exists about 20 systems of this type all over the world, and 7 among them are in Europe. PAVICOM is the only facility of such a level in Russia.

2. Technical parameters

PAVICOM consists of two independent completely automated devices PAVICOM-1 and PAVICOM-2. These devices differ from one another by the optical stage moving ranges, which determine the corresponding allowable film dimensions. The main units of PAVICOM-1 (Fig. 1, Academician E.L. Feinberg is near the installation) are the following: (1) precision-mechanics stage of MICOS system; (2) optical system completed according to the physical task to be solved; (3) a personal computer. The precision-mechanics stage MICOS consist of a massive metal platform and mobile stage which can move horizontally within the range of 400 mm × 800 mm. A digital CCD-camera is fixed above the stage and can move up and down over the interval 0–200 mm. All the coordinate determination accuracy is 0.5 μm. The optical stages and the vertical liners of PAVICOM-1 and PAVICOM-2 are moved by stepping motors controlled with computer or by joystick. The microscope optics system was manufactured in LPI and based on LOMO-produced components. The microscope optics of both PAVICOM-1 and PAVICOM-2 projects the object image on a CCD-matrix, which submits the corresponding high-quality digital image to computer. Parameters of the system are the following: 1024 grayscale levels; 1360×1024 CCD-camera pixel frame size; 4.65×4.65-μm individual cell. The automated microscope PAVICOM-2 (Fig. 2) is based on a LOMO-produced MPI-11 microscope. The PAVICOM-2 main units are the following: precision-mechanics stage DC-4x4 of Carl Zeiss Company with a control unit; (2) digital CCD-camera; (3) a personal computer. The range of the stage automated horizontal movement is 0–100 mm, the vertical displacement interval is 0–5 mm. The horizontal plane X and Y coordinates are determined with an accuracy of 0.5 μm, and the Z coordinate determination accuracy is 8.16×10^{-3} μm. In constructing the microscope at the LPI, the LOMO lenses were used. The CCD-camera parameters are the following: 256 grayscale levels; 597×537 CCD-matrix cells; 12.7×8.3-μm individual cell size. The mathematical treatment of the digitized images is carried out on computer using a $C++$ software package. The computer processing includes the object search

Fig. 1. The setup of the PAVICOM-1 system.

Fig. 2. The automated microscope PAVICOM-2.

and identification, the reconstruction ofparticle track and interaction point coordinate in the detector, and other operations. The stage movement is controlled during the measurement process by the computer with a special $C++$ software package.

3. Experiments

PAVICOM was created initially for the EMU-15 nuclear emulsion experiment. The challenge was to search for possible signals from ultra dense and ultra hot nuclear matter in the quark-gluon plasma state. However, at the present time, the PAVICOM advantages, such as universality, high operation rate, and permanent software upgrade serve not only the LPI experiment needs, but also are widely used by many other Russian laboratories and institutes. It should be emphasized that the PAVICOM group's contribution is not only to make the facility accessible. Every new experiment demands some software upgrade, apparatus modification and new methodological approach. All this work is usually done by members of the group.

"*EMU-15*" (*LPI*): An investigation of collective effects and peculiarities of the secondary-particle distribution in collisions of lead nuclei accelerated at the SPS (CERN) with an energy of 32 TeV/particle with lead target nuclei. The main goal of the experiment is to study possible signals from sub-hadronic states of high-temperature and high-density nuclear matter. The main methodological problem inherent in these investigations is associated with the large amount of measurements required in the nuclear emulsion. Evidently, such work can be performed in a reasonable time interval only with the use of some completely automated instrument of the PAVICOM type. The processed experimental data make it possible for studying peculiarities of particle angular distributions, search for unique events appearing with low probability and multiparticle correlations, which can be expected to occur in hadronization of exited nuclear matter. The distributions are examined with the help of an elaborate mathematical approach to find out signals specific for quark-gluon plasma or some other states, in which colored particles can propagate freely, for example, massive constituent quarks, if they are stable quasiparticles [5–7].

"*BECQUEREL*" (*JINR, LPI*): An investigation of the fragmentation processes of light radioactive nuclei to obtain data on secondary-particle charge states in intermediate and heavy nuclei fragmentation. The task is to study the cluster nature of nuclei and possible collective excited states of nuclear matter. Particular emphasis has been placed on multiparticle production without exchange of quantum numbers between the colliding particles (diffractive dissociation of the nuclei), which permits to look into the inner structure of one of the interacting nuclei [8].

"*STRANA*" (*LPI*): Processing and analysis of the unique gamma-hadron family with a total energy of 2×10^{16} eV. Employing the PAVICOM facility, the nuclear emulsion plates of the balloon-borne stratosphere LPI experiment with X-ray emulsion chambers were processed, which contained the unique gamma-hadron STRANA superfamily with $E_0 > 10^{16}$ eV. More then 800 showers of this family were processed in 8 nuclear emulsion layers from the emulsion chamber gamma-block. Until recently, any in-depth analysis of this family was impossible owing to the lack of appropriate measuring techniques. The PAVICOM processing will allow to understand the nature of these events and check the hypothesis of double inelastic diffraction or collective excitations of nuclear matter [9].

"*RUNJOB*" (*MSU, LPI, 7 Japanese institutes*): An investigation of nuclear composition and the energy spectrum of primary high-energy cosmic rays by direct methods [10,11]. The unique methodological feature of the RUNJOB experiment consists in employing X-ray screen-type films (two-layer X-ray films sandwiched between thin scintillator screens), which makes direct registration of cosmic ray particles by the vertex-trigger method possible. As a result, the efficiency of the search for heavy cosmic nuclei may be as much as 100%. In turn, this results in more stringent requirements imposed on both identification and processing of the detected particle tracks. Only by using the PAVICOM facility it was possible to process completely and efficiently all experimental data: heavy-nucleus tracks in the detector have been reconstructed and the charge distribution was measured for all detected particles.

"*ENERGY+TRANSMUTATION*" (*JINR, National University of Mongolia*): An examination of nuclear reactor characteristics in the sub-threshold regime [12]. A model of a uranium–lead assembly was constructed in JINR in 1999. Currently it is being tested in the proton beam at the synchrotron. Solid-state dacron-based track detectors (STD) are widely used in this experiment owing to some peculiarities of these detectors: high efficiency of fission fragment detection, low intrinsic background, and simple treatment technology. However, visual track counting for a large number of detectors (tens or even hundreds of them) presents a rather time-consuming, long-term procedure. This process can be made much easier and the number of processed detectors and their area can be increased if measurement are calculated with the automated PAVICOM facility.

"*SPECTRUM*" (*ITEP, JINR*): Experimental study of conversion electron spectra by the nuclear spectroscopy method. Switching from the microphotometry technique to the technique of microscope-emulsion measurements opens up new prospects for the investigation of internal electron conversion spectra.

"*NUCLEI*" (*INR*): An investigation of the emission of light charged particles accompanying the fission of a lead nucleus by protons, muons and pions [13]. The purpose of the experiment is to study the mechanism of interaction of protons, muons, and pions with heavy nuclei at energies from 153 to 1700 MeV as well as to obtain information on fission and on the properties of secondary nuclei which are far from β-stability. The PAVICOM facility will be used for processing data on particle emission from fragments, on cascade-evaporation processes, and on the excitation energy of high-compound nuclei.

"*CHARGE*" (*ITEP*): An analysis of the azimuthal anisotropy of multiply charged nuclear reaction products emitted normally to the reaction plane. The experiment is looking for possible manifestations of a second-type phase transition in ultra-dense nuclear matter at high temperatures. The azimuthal anisotropy of the fragment emission will be studied. This allows to determine the magnitude of the transverse energy burst, which depends on the compressibility of nuclear matter. In this way information can be obtained on the equation of state under extreme conditions.

4. Conclusions

The universality and specific capabilities of automated processing of experimental data permit to use the PAVICOM facility in a wide range of investigations where various tracking techniques are used.

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