NEVOD - experimental complex for multi-component investigations of cosmic rays and their interactions in the energy range 1 – 10¹⁰ GeV

I.A. Shulzhenko¹, M.B. Amelchalkov⁴, N.S. Barbashina⁷, A.G. Bogdanov⁵, F.A. Bogdanov⁵, A. Chiavassa², D. Gromushkin², S.S. Khokhlov⁶, V.V. Kindin¹, R.P. Kokoulin⁶, K.G. Kompaniets³, A.Yu. Konovleva¹, O.I. Likò⁴, G. Mannocchi⁷, Yu.N. Mishutina⁷, V.V. Ovchinnikov⁷, A.A. Petrukhin⁷, V.V. Shutenko⁷, Yu.V. Stanik¹, G. Trinchero⁵, V.S. Vorobiev¹, I.I. Yashin¹, K.O. Yurin¹, E.A. Zadeba¹

¹ National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), 115409 Moscow, Russia
² Dipartimento di Fisica dell' Università degli Studi di Torino, 10125 Turin, Italy
³ Osservatorio Astrofisico di Torino - INAF, 10025 Turin, Italy
⁴ Institute for Nuclear Research of RAS, 117312 Moscow, Russia

Acknowledgements: The work was performed at the Unique Scientific Facility "Experimental complex NEVOD" with the support of the Ministry of Science and Higher Education of the Russian Federation (MEPhI Academic Excellence Project No. 02.a03.21.0005) and the grant of the President of the Russian Federation (MK-3444.2019.2).

Experimental complex NEVOD (MEPhI, Russia) includes a number of detectors and installations designed to register various EAS components: electron-photon (CTS, NEVOD-EAS), muon (CWD NEVOD, CTS) and hadron (PRISMA-32, URAN) components, energy deposit of EAS cores (CWD NEVOD) and muon bundles (DECOR, TREK). All detectors and installations of the complex are combined by the global time synchronization system ensuring 10–nanosecond accuracy of timestamping of registered events to a single time source. This opens wide opportunities for conducting unique multi-component EAS studies.

Cherenkov water detector (CWD) NEVOD: 81 quasi-spherical optical modules (QSM) deployed in nodes of regular spatial lattice within a volume of 2000 m³:
- wide dynamic range (1 - 10¹⁰ phs/cm²);
- measures energy deposit of muon bundles, EAS cores, and cascades generated by single muons in the water volume.

Calibration telescope system (CTS): 80 scintillation counters (40×20×2 cm³) employed on the top and bottom of CWD tank:
- calibrates QSMs for various distances from muon tracks and Cherenkov light directions;
- separates EAS electron-photon and muon components, measures their local density spectra in ranges 10⁻¹⁵–10⁻⁹ eV and 10⁻¹⁵–10⁻⁶ eV, correspondingly.

Coordinate-tracking detector DECOR: 8 vertically arranged supermodules with a total area of ~ 70 m²;
- good spatial (<1 cm) and angular (0.7°) accuracies;
- reconstructions arrival direction, multiplicity and densities of muons in bundles of inclined EAS (up to 890°).

PRISMA-32 and URAN air-shower arrays

PRISMA-32 and URAN air-shower arrays are aimed at studying of cosmic rays in the "knee" region (~3×10²⁰ eV) by means of the detection of particles produced in interactions of EAS particles with nuclei of atmosphere or matter near the facility. In these arrays, delayed thermal neutrons generated by EAS hadronic interactions are detected over the entire area using special electron-neutron-detectors (en-detectors).

en-detectors register EAS electromagnetic (e) and hadronic (through thermal neutrons) (e) components using inorganic scintillators ZnS(Ag) + LiF (URAN) or Zn(Sn)Ag + LiF (PRISMA-32).

Light reflecting box

PRISMA-32 and URAN air-shower arrays

NEVOD-EAS air-shower array

NEVOD-EAS air-shower array: 9 independent clusters (15×15 m²) of detector stations (DS) deployed over the area of 10⁶ m² around the NEVOD;
- clusters include 4 DS with area of 2.56 m² and a dynamic range 0.3×10¹⁶ particles/m²;
- detects EAS electron-photon component in range 10¹⁴–10²⁰ eV and reconstructs EAS size, axis position and arrival direction.

Coordinate-tracking detector TREK

Large-scale coordinate-tracking detector TREK is aimed at studying of “muon puzzle” (the excess of events with a high multiplicity of muons in comparison with results of simulation obtained using contemporary models of hadronic interactions).

TREK detector:
- 264 drift chambers with effective area of 1.85 m²;
- total area of 250 m²;
- high coordinate (1 mm), angular (1.7°) accuracies, and 2-track (3.4 mm) resolution;
- will determine multiplicity and arrival direction of muon bundles passing through the CWD NEVOD water tank.

Synchronization of the Experimental complex NEVOD detectors

NEVOD-DECOR-CTS detector station

Joint event in EC NEVOD detectors